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JADS JT&E

JADS Special Report on the Costs and Benefits of Distributed Testing

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Executive Summary

1.0 Overview

The Joint Advanced Distributed Simulation (JADS) Joint Test and Evaluation (JT&E) was chartered by the Deputy Director, Test, Systems Engineering, and Evaluation[1] (Test and Evaluation), Office of the Secretary of Defense (Acquisition and Technology) in October 1994 to investigate the utility of advanced distributed simulation (ADS) technologies for support of distributed testing in development test and evaluation (DT&E) and operational test and evaluation (OT&E). In keeping with the JADS charter to explore the utility of ADS for test and evaluation (T&E), this special report provides insight into the benefits and costs associated with the use of distributed testing in developmental and operational testing. It provides program managers (PMs) with findings, conclusions, and lessons learned from the three JADS tests and other agencies regarding the costs and benefits of using distributed testing. It is the combined effort of the JADS Joint Test Force (JTF) and the MITRE Corporation's Economic and Decision Analysis Center (EDAC) and consists of two sections. The first part describes the potential benefits and cost savings arising from the incorporation of distributed testing. The second half introduces a work breakdown structure (WBS) format to support the assessment of the costs and the risks of incorporating distributed testing into the T&E process. Additionally, the second part identifies cost drivers and areas of potential risk. The two appendices present case studies where the results of previously conducted actual live tests were compared to the notional results one might have obtained had the original test been enhanced with distributed testing. Distributed testing technologies provide new capabilities that potentially help the tester overcome limitations with traditional testing. This report has generated several recommendations for the Department of Defense (DoD) T&E community. These recommendations focus on the global T&E community's needs and, if followed, will help PMs to better conduct distributed testing.

Much of the discussion concerning distributed testing for T&E infers that distributed testing is separate from other more traditional means of testing. Sometimes the use of distributed testing is described as an "alternative" to traditional testing, and costs of a test program, with and without distributed testing, are compared. Distributed testing can be thought of more precisely as a technique for bringing multiple, physically separated data sources together in a shared interactive environment. It is simply another (albeit poorly understood) tool available to the test designer. The WBS highlights where distributed testing uniquely impacts the traditional test WBS. Once distributed testing becomes more common place, the unique elements of this WBS will either become standard or will be absorbed into the definitions of the next higher elements.

[1] This office is now the Deputy Director, Developmental Test and Evaluation, Strategic and Tactical Systems.

2.0 Characterizing the Benefits of Distributed Testing

The structure of an optimal testing program should be based on the appropriate balance between cost savings and benefits. To determine the benefits of any new capability or technology there must be objective standards against which the performance of the new capability or technology is measured. These performance measures or standards can be both quantitative and qualitative. This report categorizes performance or effectiveness measures as either standards related to enhanced testing capability (is it better or faster?) or to standards related to cost reduction potential (is it cheaper?).

In deciding whether to use distributed testing, the tester should first determine its effectiveness. To do this the tester would first estimate the potential benefits of implementing distributed testing and determine any testing constraints that might limit its implementation. After identifying potential benefits and constraints, the PM would estimate the costs with and without distributed testing. Balancing the benefits and costs would allow the structure of an optimal/near optimal distributed testing program. Any feasibility analysis should provide information on when, where, and how distributed testing methods can best be applied to complement traditional test methods and enhance the overall T&E phase. The JADS experience has shown that distributed testing technologies can complement other T&E approaches but should not necessarily replace more traditional forms of testing (e.g., live testing).

To illustrate the decision process, this report outlines three possible approaches to the application of distributed testing: (1) a cost savings approach, (2) a cost neutral approach and (3) a more effective testing approach. In the first approach, substituting distributed testing for selected live testing reduces total testing costs. In the second case, distributed testing is added and the scope of other testing is reduced. The third approach adds distributed testing without eliminating any live testing, so that total costs are higher but with the benefit of improved testing.

3.0 Cost Guidance

The second half of the report, written by MITRE Corporation's EDAC and supported by JADS, provides cost guidance to help the PM make cost estimates. This section provides information that T&E organizations may find useful in costing testing methods and processes.

The cost guidance is based on the JADS test experience and is presented at a level above a cost model. As a result, it is a useful first step in supporting a given program's distributed testing cost estimating efforts. For example, the cost guidance addresses cost drivers, major areas of risk, risk mitigation and lessons learned. Although the cost guidance falls short in providing a complete estimate of distributed testing costs for every specific requirement, it will help PMs begin to determine the costs of incorporating distributed testing into their T&E program.

1.0 Overview

The purpose of this special report is to provide insight into the benefits and costs associated with the use of advanced distributed simulation (ADS) in developmental and operational testing. It is the combined effort of the Joint Advanced Distributed Simulation (JADS) Joint Test Force (JTF) and the MITRE Corporation's Economic and Decision Analysis Center (EDAC) and consists of two sections. The first section discusses the overall potential benefits and cost savings associated with the use of distributed testing for test and evaluation (T&E). The second provides cost guidance for incorporating distributed testing into the T&E phase of a developmental program and structures information collected from the three JADS tests, as well as information from other agencies using distributed testing, into a work breakdown structure (WBS), a common program management format. The two appendices present case studies where the results of previously conducted actual live tests were compared to the notional results one might have obtained had the original test been enhanced with distributed testing.

1.1 Background and Assumptions

This report relies on JADS findings, results, and lessons learned. The Office of the Secretary of Defense chartered JADS in October 1994 to investigate the utility of distributed testing for T&E. The JADS program consists of three multiphased test programs: the System Integration Test (SIT) explored distributed testing of precision guided munitions (PGM); the End-to-End (ETE) Test investigated distributed testing of command, control, communications, computers, intelligence, surveillance and reconnaissance (C4ISR) systems; and the Electronic Warfare (EW) Test examined distributed testing of EW systems. For further information on these tests consult the JADS website at http://www.jads.abq.com/html/jads/jads.htm.[2]

Much of the discussion concerning distributed testing for T&E infers that distributed testing is separate from other more traditional means of testing. Sometimes the use of distributed testing is described as an "alternative" to traditional testing, and costs of a test program, with and without distributed testing, are compared. Distributed testing can be thought of more precisely as a technique for bringing multiple, physically separated data sources together in a shared or real devices or people. The virtual battle space or test space created by the interactions of the data sources is indeed a "model" because the virtual space is a representation of reality. It is not, however, a model in the traditional sense. It is not lines of code being processed in a single machine or multiple machines linked together. Within distributed testing, it is feasible to have a cast of players who are all "real" -- perhaps even operating in a real environment. In such a case, it is possible to generate and collect traditional test data. That is very different from a stand-alone model where actual test data must be put into the model. Even in cases where live, virtual, and constructive data sources are mixed, the system under test (SUT) may be the real thing and the

[2] After 1 March 2001 refer requests to Headquarters Air Force Operational Test and Evaluation Center History Office (HQ AFOTEC/HO), 8500 Gibson Blvd. SE, Kirtland Air Force Base, New Mexico 87117-5558, or Science Applications International Corporation (SAIC) Technical Library, 2001 North Beauregard St., Suite 80, Alexandria, Virginia 22311.

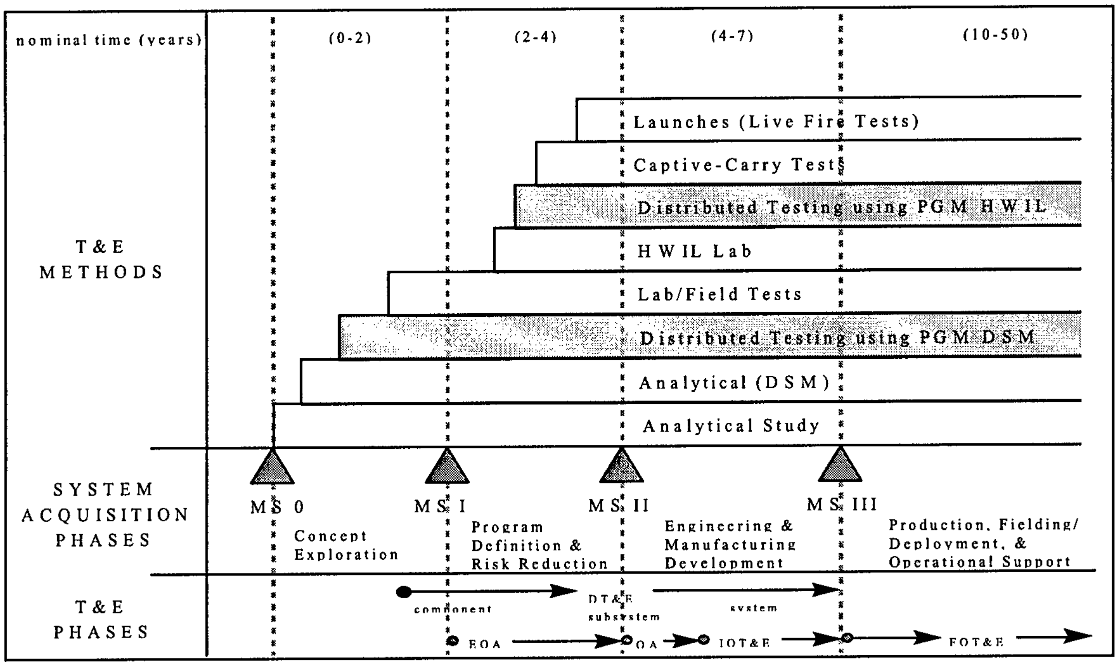
virtual environment can supply measurable stimuli for testing. The key difference between a distributed testing architecture "model" and a constructive "model" is the direction of flow of test information. In the distributed testing case, the flow can be from the SUT to the analyst. In the constructive case, the analyst must incorporate test data into the model, and the lines of code generate output for the analyst. In the latter case the output might be thought of as the analytical conclusion of the model. If the analyst doesn't like or believe the output he or she can manipulate input data, model parameters, or algorithms to "adjust" the answers. The constructive model may yield a variety of insights, but it does not provide "test" data as the distributed testing environment can. Additionally, where human beings are important elements of testing, the distributed testing environment supports their participation. Constructive models have historically had trouble realistically representing human processes.

1.2 The Use of Distributed Testing as Part of the Total Acquisition Process

The use of distributed testing technologies is not limited to operational test and evaluation (OT&E) and developmental test and evaluation (DT&E). The technology can support the other testing phases: early operational assessment (EOA), operational assessment (OA), initial operational test and evaluation (IOT&E), and follow-on operational test and evaluation (FOT&E) of an overall acquisition program.

For example, Figure 1 illustrates the role of distributed testing during a precision guided missile (PGM) system acquisition and testing life cycle. Similar diagrams can be constructed for most system development efforts. A PGM digital system model (DSM) normally becomes available during the initial system acquisition phase, so that evaluations can begin during this phase (e.g., for requirements development), even before formal T&E begins. The optimal use of the various methods depends on the PGM performance areas being evaluated. Note from Figure 1 that distributed testing can be used throughout the system acquisition and testing life cycle as PGM simulation resources are developed and refined. Although similar illustrations are not presented for EW and C4ISR systems, distributed testing can be used throughout the acquisition and testing life cycles of those types of systems as well.

DSMs are expected to be more common as Simulation Based Acquisition takes hold. While JADS did not use DSMs in the PGM test, JADS did use a DSM in the EW Test and in the C4ISR test. In the EW Test, JADS used a DSM of an airborne self-protection jammer interacting with manned threat simulators in a geographically separate facility to recreate an open air test. The DSM in this test represented a very early system model capable only of simulating the jammer logic and decision cycle times. This shows how T&E methods can be brought to bear as soon as there are system components or subcomponents available, even if the system component is only the DSM. As system acquisition proceeds, broader ranges of T&E methods can continue to be used to test the evolving system and subsystems. The JADS C4ISR test used a more evolved type of DSM constructed primarily from the systems operational software coupled with models of the platform sensor. The resulting DSM was suitable for system OT&E, training, and future operational flight program (OFP) development.



DSM = digital system model HWIL = hardware-in-the-loop MS = milestone

Figure 1. Role of Distributed Testing During PGM System Acquisition and Testing Life Cycle

1.3 Benefits of Implementing Distributed Testing

The structure of an optimal testing program should be based on the appropriate balance between cost savings and benefits. To determine the benefits of any new capability or technology there must be objective standards against which the performance of the new capability or technology is measured. These performance measures or standards can be both quantitative and qualitative. This report categorizes performance or effectiveness measures as either standards related to enhanced testing capability (is it better or faster?) or to standards related to cost reduction potential (is it cheaper?).

1.3.1 Enhanced Test Capability

JADS demonstrated that distributed testing can overcome many of the traditional limitations and problems with test and evaluation. Distributed testing allows a richer, more reactive environment to be created earlier in system development. Traditional single model or model versus model analysis is not as reactive as simulations where human intelligence is allowed to affect appropriate system actions. Human operators are an integral part of many weapon systems and need to be part of early system testing if possible. For example, using models to determine jammer effectiveness against manned threats ignores the human operator's ability to recognize the target in the jammed display increasing the risk that the jammer will be ineffective. By allowing the digital model to interact with the manned threat simulators, distributed testing allows the system developer to reduce the development risk by measuring jammer effectiveness early on. In the

PGM example, linked laboratories could provide reproducible, higher confidence results. Missile testing using a linked laboratory distributed testing architecture is more reproducible than live testing because scenario conditions are more readily controlled and trials can be replayed for additional PGM responses. This allows more trials to be combined for analysis, giving greater confidence in evaluation results. Distributed testing also injects more realism than analytical models since actual hardware is used, and linked simulation is often more realistic than stand-alone hardware-in-the-loop (HWIL) laboratories. Distributed testing allows the test designer to take advantage of the laboratory's inherent abilities to provide secure evaluation of classified electronic countermeasures (ECM) techniques and to increase force density or representation through the use of simulation. In the C4ISR arena, distributed testing allows the force density of the scenario to be increased affordably. The number of friendly and threat systems can be increased by representing them with either manned laboratories (if realistic man-in-the-loop control of the systems is needed) or DSMs (if scripted behavior is acceptable). The inability to evaluate system performance in combat-representative environments is a common limitation in OT&E and an area in which distributed testing can improve the operational test (OT) environment. The ability of distributed testing to create affordable, large-scale and complex environments for the SUT could mean more thorough testing. That, in turn, could provide early identification of problems that might otherwise go unnoticed. There is also a potential for reducing test duration by using multiple facilities in an integrated environment rather than using them sequentially.

JADS found utility for distributed testing in each of the areas investigated. Key areas of utility are described below.

1.3.1.1 Precision Guided Munitions Enhanced Test Capability

The SIT investigated the ability of distributed testing to support air-to-air missile testing. The test included two sequential phases, a Linked Simulators Phase (LSP) and a Live Fly Phase (LFP). Both phases incorporated one-versus-one scenarios based upon profiles flown during live test activities and limited target countermeasure capability.

The LSP distributed architecture incorporated four nodes: the shooter, an F/A-18 manned avionics laboratory at China Lake, California; the target, an F-14 manned avionics laboratory at Point Mugu, California; a HWIL missile laboratory at China Lake which hosted an air intercept missile (AIM)-9M missile; and a test control center initially located at Point Mugu and later relocated in the JADS facility in Albuquerque, New Mexico.

The LFP distributed architecture linked two live F-16 aircraft (a shooter and target) on the Eglin Air Force Base, Florida, Gulf Test Range; the Eglin Central Control Facility; an HWIL missile laboratory at Eglin which hosted an AIM-120 missile; and a test monitoring center at the JADS facility in New Mexico.

This report describes the outcome of the SIT, the conclusions and lessons learned, and offers observations on the implications of SIT for the general class of precision guided munitions.

1.3.1.1.1 System Integration Test Results and Conclusions

Within the narrow confines of the SIT data, our assessment is that the two architectures we employed have utility for support of T&E. The JADS data indicate that activities ranging from parametric analyses to integrated weapons system testing are both practical and cost effective. Our broad conclusions and lessons learned can be summarized as follows.

- For T&E applications, the technology is not at the "plug-and-play" stage. While practical and cost effective in many cases, implementation is more challenging than many people think. Plan for a lot of rehearsals and "fix" time.

- The effects of latency and other ADS-induced errors can often (not always) be mitigated.

- Synchronization is as much a challenge as latency.

- Instrumentation and data management are challenges.

- ADS has great potential as a T&E support tool; it is a valuable addition to the tester's tool kit. ADS will not obviate, but in some cases it may reduce, the need for live testing.

- Our data suggest test savings are possible.

1.3.1.1.2 Observations for Precision Guided Munitions T&E

As JADS demonstrated in the System Integration Test, the live shooter-target distributed testing architecture can be used for realistic one-versus-one engagement tactics development and evaluation. Distributed testing exhibits more realism than either analytical simulation models (because actual hardware is used) or stand-alone HWIL laboratories (because realistic shooter and target inputs are provided).

Shooter/PGM integration can be effectively evaluated using distributed testing configurations. Integration check-out can begin early in the acquisition cycle before a complete PGM system is available by using the linked laboratory distributed testing configuration and including only key PGM subsystems in the PGM HWIL laboratory. Note that this same configuration can also be used to verify the integration of a new shooter platform into an existing PGM system. If the PGM receives data link support from the shooter during its flyout, the live shooter-target distributed testing configuration can be used to accurately evaluate the quality of the support messages and the resulting interactions.

Testing using a live shooter-target distributed testing architecture is more efficient than live shot testing because the analysts get immediate feedback on each trial of a multiple trial mission. This allows adjustments to be made to the remaining test matrix, if necessary, while the live shooter and target platforms are still on range. This "analyst-in-the-loop" feature of distributed testing would be especially useful in efficiently progressing through an ECM testing matrix which involves varying a number of ECM-related parameters. (Up to 15 trials were executed during each two-hour SIT LFP mission.)

Live fire tests can be realistically rehearsed using distributed testing. This would ensure the proper setup of the scenario and reduce wasted live fire attempts in which the proper scenario conditions are not achieved or would result in anomalies (i.e., cost avoidance). This use of distributed testing would also reduce the risk of a live fire testing program by identifying scenarios that cannot be correctly executed or which cannot achieve the stated objectives.

Also, distributed testing implementation may benefit other parts of the PGM acquisition program besides testing. Distributed testing using a DSM to represent the PGM may aid in requirements development, and resources developed during distributed testing implementation may be useful for training. Such benefits of distributed testing implementation that are beyond the normal scope of testing should also be considered in this determination. The distributed testing architecture also can support real-time distribution of test results to appropriate analytical agencies not involved in testing. There may be significant efficiencies in planning for future test events or assessing the need for system improvements.

Through a process of inductive reasoning we can transfer some of the SIT-based specifics to the general class of PGM. In the general case, the elements of the SIT architectures are basic to all PGM cases. There are (1) a launch platform or shooter, (2) a PGM, (3) an intended target, (4) an operating environment (to include countermeasures), and (5) a test control center.

The shooter, PGM, and target can be represented in any of the three forms associated with distributed simulation: live, virtual, or constructive. SIT looked at an AIM-9 and an AIM-120. The physical dynamics of the problem are comparable with any class of PGM. The physics associated with detection, tracking, and guidance may differ significantly depending upon bands, techniques, and the operational medium a missile operates in. We do not see a one-for-one transfer of SIT techniques to other tests. Each test has specific requirements, often peculiar to the particular system under test. We do see a transfer of the principles, design processes, and methodologies used in SIT.

Testing using manned shooter and target simulators linked to a PGM DSM or HWIL laboratory can be used to realistically evaluate man-in-the-loop reactive countermeasures (CM). This cannot be done in live fire testing because of obvious safety constraints. It is also possible to create launch profiles that examine missile performance under conditions too dangerous to fly. CM were only represented in rudimentary form in the SIT, but we see no technical impediments, at the conceptual level, to implementing high-fidelity countermeasures in distributed testing. The actual costs and technical challenges will be very case specific. Complex environmental details associated with atmospherics, space, oceanography, etc., are more challenging. In the SIT case, the LFP incorporated real atmospheric effects.

A test control center is a requirement for all testing, distributed or not. Fortunately, the SIT experience suggests that the control center can function from almost anywhere. The inference is that an existing control center somewhere may well meet a specific tester's needs.

The SIT program was budget and schedule constrained. Consequently, there were important aspects of PGM testing which SIT did not explore. From a single shooter perspective, some of these included multiple launches against a single target, single launches against clustered targets, and multiple launches against multiple targets. SIT did not examine few-on-few or many-on-many scenarios. Our expectation, unsupported by hard data, is that few-on-few implementations are possible. The difficulties and costs would be extremely sensitive to the fidelity requirements and the availability of existing facilities, e.g., HWIL facilities or installed systems test facilities.

The SIT results suggest strongly that ADS has good potential for improving PGM testing. The implication is that test planners should consider the technology as a relevant tool for their program until an objective assessment suggests otherwise.

1.3.1.2 Command, Control, Communications, Computer, Intelligence, Surveillance, and Reconnaissance Enhanced Test Capability

The ETE Test evaluated the utility of ADS to support testing of C4ISR systems. The test used the Joint Surveillance Target Attack Radar System (Joint STARS) as one component of a representative C4ISR system. The ETE Test also evaluated the capability of the JADS Test Control and Analysis Center (TCAC) to control a distributed test of this type and to remotely monitor and analyze test results.

The ETE Test consisted of four phases. Phase 1 developed or modified the components needed to develop the ADS test environment. Phase 2 used the ADS test environment to evaluate the utility of ADS to support DT&E and early OT&E of a C4ISR system in a laboratory environment. Phase 3 transitioned portions of the architecture to the E-8C aircraft, ensured that the components functioned properly, and checked that the synthetic environment correctly interacted with the aircraft and actual light ground station module (LGSM). Phase 4 evaluated the ability to perform test and evaluation of the E-8C and LGSM in a synthetically enhanced live test environment.

The test concept was to use ADS to supplement the operational environment experienced by the E-8C and LGSM operators. By mixing available live targets with targets generated by a constructive model, a battle array approximating the major systems present in a notional corps area of interest was presented. By constructing a network with nodes representing appropriate command, control, communications, computers and intelligence (C4I) and weapon systems, a more robust cross section of players was available for interaction with the E-8C and LGSM operators.

The TCAC, in Albuquerque, New Mexico, provided test control.

The ETE Test used the Janus 6.88D simulation to generate the entities representing the elements in the rear of a threat force. The U.S. Army Training and Doctrine Command Analysis Center (TRAC) at White Sands Missile Range (WSMR), New Mexico, provided the Janus scenario feed.

Bravo Company, 303d Military Intelligence Battalion represented the LGSM and target analysis cell (TAC). Fire support, in the form of the Advanced Field Artillery Tactical Data System (AFATDS), was represented by soldiers from the 4th Infantry Division (Mechanized).

Communications among these systems employed such doctrinally correct means as the CGS-100, a subsystem of the Compartmented All Source Analysis System (ASAS) Message Processing System (CAMPS), remote workstations (RWSs), and AFATDS message traffic.

The Tactical Army Fire Support Model (TAFSM) simulation modeled the Army Tactical Missile System (ATACMS) battalion and sent the fire and detonate protocol data units (PDUs) to the Janus 6.88D simulation. Janus then modeled the engagement results and reflected them in the synthetic environment.

The Joint STARS E-8C simulation, called the Virtual Surveillance Target Attack Radar System (VSTARS), represented the radar subsystem of the Joint STARS E-8C in a laboratory environment. It was composed of a distributed interactive simulation (DIS) network interface unit (NIU), a radar processor simulator and integrator (RPSI) that contained the two real-time radar simulations with necessary databases, and various simulations of E-8C processes. VSTARS was operated at the Northrop Grumman Surveillance and Battle Management Systems facility in Melbourne, Florida.

1.3.1.2.1 End-to-End Test Results and Conclusions

Within the narrow confines of the ETE Test data, our assessment is that the architecture we employed has utility for support of T&E. The JADS data indicate that DT&E and OT&E activities incorporating ADS technology are both practical and cost effective. Our broad conclusions and lessons learned can be summarized as follows.

- An ADS environment can enhance C4ISR system DT&E and OT&E. In comparison with conventional tests, ADS allows testers to examine C4ISR systems under realistic conditions for longer periods of time, over far larger battlespaces, and at a much lower cost. This versatile technology can provide test environments that include large numbers of entities, entities operating under realistic but unsafe conditions, and joint and combined operations. ADS provides C4ISR system testers with greater flexibility in designing, executing, and analyzing their tests. During DT&E, ADS allows for more realistic compliance testing of C4ISR subsystems and efficient implementation of the test-fix-verify cycle for software development.

- ADS testing provides dramatic abilities to test C4ISR systems or components in that system. For instance, in the ETE Test ADS environment, a developmental test could be performed on the Joint STARS operations and control subsystem using VSTARS as a stimulus. With a similar configuration, an operational test could be accomplished on a LGSM. The ETE Test ADS environment also provides ample opportunities to install new components for various types of testing. Links to airborne weapon system simulators, complimentary sensor feeds or other command and control structures can be easily accomplished. The development of an

ADS test environment during system development greatly improves opportunities for C4ISR system training after the completion of the test. The same infrastructure developed for testing can be modified and transitioned to a training environment resulting in program savings. This technology allows C4ISR system operators to confirm current tactics, try "what-if" scenarios and new tactics, test the interoperability and compatibility of their equipment, and gain useful experience in a realistic operating environment containing multiple assets.

- The ETE Test required only a small part of the available bandwidth and exhibited a low PDU latency rate. The ETE Test network was highly reliable during testing, due largely to the ETE Test team's extensive pretest risk reduction efforts.

- Compared to conventional testing, ADS testing reduces the need for large numbers of fielded personnel and vehicles. The ability to automatically collect and analyze test data also reduces the number of people required for setup, execution, and analysis. ADS test success relies on well-organized test control and data management procedures. Distributed testing requires sophisticated instrumentation, trained personnel to operate and maintain that equipment, and funds to support personnel and equipment at distant test nodes.

- Testers should carefully plan the development of the simulations and links comprising their ADS environment. During test execution, they must ensure that the time sources are synchronized and continuously monitor PDU traffic. The distributed nature of ADS testing necessitates special equipment for network checkout and verification and requires strict configuration control of analysis tools and collected data.

- ADS test planning should be detailed enough to encompass key requirements at the earliest possible stages, yet flexible enough to accommodate unexpected situations during test execution.

- A conservative development approach is recommended. Accomplish risk reduction activities before each ADS test and let each ADS test build on the success of earlier experiments. Successful test execution requires effective internode communication, test and resource control, and data management procedures.

1.3.1.2.2 Observations for C4ISR T&E

Through a process of inductive reasoning, we can transfer some of the specifics of the ETE Test to the general class of C4ISR systems. In the general case, the elements of the ETE Test architecture are basic to all mission-level testing of C4ISR systems. In other words, there is a shooter, a sensor, an intended target, an operating environment, and a test control center.

The shooter, sensor, and target can be represented in any of the three forms associated with distributed simulation: live, virtual, or constructive. We do not see a one-for-one transfer of ETE Test techniques to other tests. Each test has specific requirements, often peculiar to the particular system under test. However, we do see a transfer of the principles, design processes, and methodologies used in the ETE Test.

Technically, it's not impossible to develop a high-fidelity operating environment in ADS. However, the costs and challenges will vary from test to test and will depend on the desired level of complexity.

A test control center is a requirement for all testing, distributed or not. Fortunately, the ETE Test experience suggests that the control center can function from almost anywhere. Thus, a specific test may save resources by using an existing control center.

The ETE Test results strongly suggest that ADS has excellent potential for improving C4ISR testing. Thus, test planners should consider the technology as a relevant tool for their program until an objective assessment suggests otherwise.

1.3.1.3 Electronic Warfare Enhanced Test Capability

The EW Test evaluated the utility of ADS to support EW T&E. While the test used several efforts to examine ADS-based T&E, the cornerstone effort was a series of traditional and ADS-based test events using an airborne self-protection jammer. This effort was called the self-protection jammer (SPJ) test. The SPJ test defined a simple, repeatable test scenario. The scenario was executed in three traditional test environments to create a data baseline. The test scenario was then executed in two ADS-enhanced test environments. The first ADS-based test event used a real-time DSM interacting with manned threat simulators at the Air Force Electronic Warfare Environment Simulator (AFEWES) facility. The second ADS-based test used the SPJ installed on an F-16 suspended in the anechoic chamber at the Navy's Air Combat Environment Test and Evaluation Facility (ACETEF). The data from all tests were statistically compared in an attempt to quantify the impacts of ADS.

1.3.1.3.1 EW Test Results and Conclusions

Within the confines of the SPJ test data, JADS concluded that ADS architectures that allow the capabilities of geographically separated facilities to be combined to create a realistic test environment for EW devices can be designed. This allows the same test environment to be used for SUT representations ranging from DSMs to operational equipment. Testing in a common ADS-based environment represents a significant departure from the traditional sequential EW test process. EW Test key results are identified.

- Designing ADS architectures requires a close team comprised of several technical experts spanning several disciplines directed by a system integrator.

- The architecture produced valid results for both the DSM and actual jammer hardware.

- Latency within the closed-loop interaction was aggressively managed, and JADS was able to meet its objective for more than 95% of the runs.

- The high level architecture (HLA) appears to be a feasible method for linking simulations for

T&E. It is appropriate to use HLA to link to other HLA-compliant simulations/simulators, but the T&E community should not view it as the only architecture to consider when designing distributed tests.

- Two of the eleven EW test facilities surveyed in 1996 as part of the Threat Simulator Linking Activity (TSLA) effort that were appropriate for ADS-based testing have been closed. While this is a significant erosion in the infrastructure needed to design and execute ADS-based tests, it already limits the traditional EW testing process.

1.3.1.3.2 Observations for EW T&E

JADS assessment, based on the different EW Test efforts, is that ADS has varying levels of utility for EW T&E. These levels of utility depend on the nature of the EW device being tested and the availability of suitable test facilities. Single function EW devices and federated EW systems are expected to benefit least from an ADS-enhanced test process. Only radio frequency (RF) jammers may see sufficient benefit to outweigh the additional cost of an ADS-enhanced test process. Integrated EW systems may see significant benefits where a single test facility is not capable of providing all the stimulation (including the closed-loop SUT versus manned threat interaction for systems that include RF jammers) needed to simultaneously test all the particular integrated EW system's functions. Systems of systems testing such as that required for electronic support (ES) systems should see significant benefits in ADS-based testing. By breaking through traditional facility barriers and allowing multiple facilities to participate in the same test event, the following types of test events are possible.

Combined DSM/ hardware-in-the-loop (HITL) events. JADS demonstrated this in Phase 2 of the SPJ test. This combination allowed a real-time DSM to interact with manned threats before any actual SUT hardware was developed. Problems found here are quite inexpensive to fix. Additionally, this may provide a way to gain confidence that the DSM is behaving as the real hardware which in turn may increase confidence in model-on-model excursions to expand the test envelope. This also allows the possibility to directly compare dissimilar technology during an analysis of alternatives. Here the limitation is that the model must run in real time. This is more strict than compliance with either the Joint Modeling And Simulation System (JMASS) or the HLA.

Combined system integration laboratory (SIL)/HITL events. Breadboard and brassboard hardware can be transported to the HITL and tested today. Leaving the SUT in its development site may reduce the time required to solve problems that are encountered and also allows the other offensive or defensive systems and operators to play in an environment with manned threats. This means more realistic and reactive testing early. Here the limitation is the capability of the stimulators to recreate the environment.

Combined HITL/installed systems test facility (ISTF) events. This expands tests where the SUT is integrated with the host platform. JADS demonstrated this in the Phase 3 test. Traditionally this is where electromagnetic interference (EMI)/compatibility (EMC) testing occurs and stimulation is limited to what the ISTF can provide. Manned threats are not usually located in ISTFs. The HITL/ISTF combination allows closed-loop effectiveness testing to occur at the same time as EMI/EMC testing. This should avoid sequential testing should fixes to EMI/EMC testing impact the SUT.

Combined open air range (OAR)/HITL events. This expands or improves the threat set that can be applied. Manned semi-active threats can be combined with remote seekers to improve the missile flyout simulation. Unmanned training emitters can be used with HITL operators to add threats. In this case the live platform position can be sent to the HITL allowing those threat operators to engage a synthetic target. The threat modes and actions are sent back to the OAR and recreated by the training emitter.

Connecting facilities derives additional benefits. Both integrated systems and systems of systems are expected to benefit from distributed testing.

Adequate testing of integrated systems requires a simultaneous test of all integrated EW functions to include closed-loop SUT/manned threat interactions in a common environment in a single test event. It is possible to separate the functions and test each sequentially. However, this adds risk to the acquisition decision. Where a single facility is capable of testing an integrated EW system to this level, ADS is expected to provide limited benefit. ADS offers the opportunity to use existing facilities instead of expanding a single facility to provide an adequate level of test capability.

EW systems are not limited to single platform scenarios. The class of EW systems called electronic support deals with system of systems EW actions. Testing a system of systems traditionally occurs either in model-on-model or OAR events. Both are limited and OAR events can be quite expensive. More importantly, by creating a reactive, operationally realistic environment through ADS, the contribution of EW systems may be captured directly in mission-level measures of effectiveness.

1.3.2 Cost Reducing Potential

Another way of categorizing the benefits relates to the cost reducing potential of distributed testing. The use of distributed testing may directly result in cost savings and/or reduce overall program costs by avoiding costs.

1.3.2.1 Cost Savings

Live tests requiring that multiple platforms be brought to and assembled at a test range is one example of the type of test that, for some cases, would be more efficiently and effectively accomplished through distributed testing or would at least support reduction in the number of expensive live tests required. Software (SW) developed for distributed testing may be reused to support traditional testing methods. One example of this is from the JADS SIT LFP. The special purpose interface developed to connect aircraft to the Advanced Medium Range Air-to-Air Missile (AMRAAM) ground lab was later used for troubleshooting in traditional testing methods. The VSTARS is probably the best example of SW developed for distributed testing with reuse capability. However, more than software fits in this category. For example, the AFEWES manned simulators were used for decades in traditional T&E. They were used by JADS for ADS-based testing by adding an interface to the facility. Any potential overlap between traditional and distributed testing methods should be addressed by the feasibility analysis.

The empirical data from the JADS tests have provided the JTF, already experienced in conventional T&E techniques, with sufficient confidence to identify benefits and savings arising from the use of distributed testing. Several uses for distributed testing technologies have been identified that support cost savings for traditional tests and across the program that should be considered when assessing the cost of distributed testing to the overall program.

- Distributed testing analysis results can indicate where live testing can best be focused and may reduce the need for some live tests.

- Distributed testing results in a synthetic environment (SE) that can support other areas of the program, other programs, and other Department of Defense (DoD) initiatives. For example:
  - The SE capability supports system design and development, training simulation, and training for the live test community.
  - It can be used for early operational assessments, development of tactics, techniques and procedures before system testing, test rehearsal, verification of data sources and data reduction techniques, and to determine whether adequate data are collected to evaluate test measures.
  - In some cases, other systems' test programs that require similar input can reuse an SE (e.g., the ETE Test SE, with minor upgrades, could be reused for the Block 2 ATACMS OT&E.

The Simulation Based Acquisition (SBA) and Simulation T&E Process (STEP) initiatives will advance more quickly as programs initiate development of SEs as a normal step in the program's life cycle. The focus of SBA is reduced cycle time - the ability to use the technology to develop systems more rapidly, reducing the current major system cycle time from 15-20 years to 7-10 years (50 percent). Currently, most systems progress through a series of sequential tests at multiple facilities using the unique capabilities of the individual facilities to address different test objectives. Distributed testing technologies can be used to link the individual facilities and conduct concurrent testing of multiple test objectives, thus providing the opportunity for significant time and cost savings. If shortening the acquisition timeline results in cost savings, then there is a powerful argument for using the technology. Major test programs often employ a variety of tools including physical models, force-on-force models, HITL facilities, open air testing, SIL, simulators, measurement facilities and the like. In some cases, testers take advantage of large-scale field exercises (which are becoming increasingly rare). In many cases, the SUT must be moved from facility to facility in a sequential stream. Because of scheduling issues with high use facilities, there is often a significant amount of slack in test program time lines. Where large-scale field exercises are a test vehicle of choice, there may be a year or more between test opportunities. Additionally, the use of distributed testing can reduce total testing costs by replacing a limited number of live tests with distributed tests.

1.3.2.2 Cost Avoidance

Cost avoidance is the notion that distributed testing can help perform more complete testing earlier in a program and identify failure modes and other problems earlier when they can be fixed cheaper and in less time than when they are discovered later in the system's life cycle. For example, the ability of distributed testing to incorporate man-in-the-loop provides an opportunity for cost avoidance when the technology is used as a test rehearsal and training tool. Test participants can climb the early part of the learning curve in the virtual environment, and the test schemes can be refined prior to using very expensive test facilities. The time associated with lost test events could therefore be reduced. In some situations distributed testing can reduce the risk and cost of wasted live fire attempts by providing a realistic test rehearsal capability. More thorough testing should result in identification of system deficiencies earlier in the life cycle when they can be fixed more efficiently, thus saving schedule and dollars. Distributed testing can redo live tests that have encountered problems more quickly than live retesting which would result in schedule slips. Traditional tests are still required, but by reducing the number of lost test events, you can save money over all.

Testing could be more thorough, could complete more test scenarios, and could be used for cases where live tests are limited by test range constraints, weather, equipment, or when the test environment needs to be very complex. For example, the Joint STARS Multiservice Operational Test and Evaluation (MOT&E) was originally planned to be conducted over the National Training Center at Fort Irwin, California, with 300-500 military vehicles in the maneuver area. Background traffic from Los Angeles, California, and Interstate 10 would have provided a more operational load on the system, however, would not have provided an increased load on the operators. This approach was taken because the test planners realized they would never be able to provide an operationally representative test environment short of an actual war. The JADS ETE Test was able to represent 10,000 vehicles arranged and maneuvering in a doctrinally correct threat laydown of enemy corps. This provided a much more representative operational environment to perform operational testing and provided the testers with a repeatable environment where ground truth was known.

1.4 Deciding Whether to Use Distributed Testing Technology

In deciding whether to use distributed testing, the tester should first determine its cost effectiveness. To do this the tester would first estimate the potential benefits of implementing distributed testing and determine any testing constraints that might limit its implementation. To help determine the feasibility and utility of distributed testing test methods, JADS published *A Test Planning Methodology – From Concept Development Through Test Execution* which can be found at www.jads.abq.com.[3] This report provides a well-defined process to support the feasibility analysis presented in the proposed WBS element 1.X.0. This should cover the technical requirements of the system's tests, the performance metrics needed, risks associated with not using distributed testing test methods (e.g., insufficient testing), and rough order of magnitude (ROM) costs and schedule estimates.

After identifying potential benefits and constraints the PM would estimate the costs with and without distributed testing. Some cost considerations when deciding to use distributed testing are the availability of a DSM for the project, fidelity and complexity of the technical requirements, and availability and maturity of other federation entities. Balancing the benefits and costs would allow the structure of an optimal/near optimal distributed testing program. Any feasibility analysis should provide information on when, where, and how distributed testing methods can best be applied to complement traditional test methods and enhance the overall T&E phase. The JADS experience has shown that distributed testing technologies can complement other T&E approaches but should not necessarily replace more traditional forms of testing (e.g., live testing).

To illustrate the decision process, this report outlines three possible approaches to the application of distributed testing: (1) a cost savings approach, (2) a cost neutral approach and (3) a more effective testing approach. In the first approach, substituting distributed testing for selected live testing reduces total testing costs. In the second case, distributed testing is added and the scope of other testing is reduced. The third approach adds distributed testing without eliminating any live testing, so that total costs are higher, but with the benefit of improved testing.

In the case of reduced testing costs, the total testing budget is reduced (although the total program budget would undoubtedly be kept fixed, providing more "cushion" to the overall program) because distributed testing allows the scope of the expensive live testing to be significantly reduced and because the distributed testing costs are less than the live tests replaced. This approach would be very case specific and problematic for the PM, since some live testing is required and the number of live trials is usually minimal anyway.

In the case of costs remaining the same, the total testing budget is kept fixed, and distributed testing is added by reducing the scope of testing with the other techniques (i.e., the zero sum approach), including the expensive live testing. In this case, distributed testing has no cost impact or savings (cost neutral), since the total testing budget is unchanged. The justification in this case would be that distributed testing allows you to do better tests which would reduce the potential for expensive fixes later in the program. The last scenario would apparently involve increased testing costs, but if waste of time and resources is avoided costs may balance out.

In the case of increased testing costs, distributed testing is added without changing the scope of the other testing techniques. Given this approach, the expectation would be that the enhanced

[3] After 1 March 2001 refer requests to Headquarters Air Force Operational Test and Evaluation Center History Office (HQ AFOTEC/HO), 8500 Gibson Blvd. SE, Kirtland Air Force Base, New Mexico 87117-5558, or Science Applications International Corporation (SAIC) Technical Library, 2001 North Beauregard St., Suite 80, Alexandria, Virginia 22311.

testing would pay for itself in delivery of a better system to the end user, or that system deficiencies that may go undetected without distributed testing could be addressed earlier with attendant cost savings.

2.0 Cost Guidance

Section 1 discussed the potential to either save on costs or to avoid costs. It proposes three cases where a program manager may need to estimate costs or perform cost trade-offs between possible test methodologies. This section provides cost guidance to allow the program manager to make estimates and perform the trade-offs. Developed by MITRE Corporation's EDAC and supported by JADS, this section provides information that T&E organizations may find useful in costing testing methods and processes.

2.1 Purpose and Focus

Initially, JADS considered developing a parametric model to estimate the costs of employing distributed testing in the DT&E phase of system acquisition or the costs of using distributed testing for OT&E. JADS was to develop the model from information collected during the execution of the three JADS tests. As it turned out, however, this was not practical. The tests did not provide enough of a database to develop a parametric model. Specific cost information was not collected to the level necessary for the development of a parametric cost model, largely because of the lack of insight into the internal cost accounting of the various test organizations and laboratories JADS worked with. Additionally, JADS cost data were specific only to our particular tests. Although such data might provide some indication of the costs of using distributed testing in a similar program, they do not necessarily provide information relevant to other specific system types. Therefore the cost guidance that follows is based on the JADS test experience and is presented at a level above a cost model. As a result, it is simply a useful first step in supporting a given program's distributed testing cost estimating efforts. For example, the cost guidance addresses cost drivers, major areas of risk, risk mitigation and lessons learned. Although the cost guidance falls short in providing a complete estimate of distributed testing costs for every specific requirement, it will help PMs begin to determine the costs of incorporating distributed testing into their T&E program.

2.1.1 Cost Guidance Section Contents

This cost guidance section focuses on those T&E activities where distributed testing potentially has an impact. Available cost data were reviewed and key subject matter experts were interviewed to determine potential cost drivers, lessons learned, risks, and risk mitigation strategies. It includes information pertaining to the identification of relevant cost elements for using distributed testing for T&E. This section also provides lessons learned, identifies potential risk areas, and identifies tools to support the use of distributed testing.

This section includes information on the cost guidance purpose, intended use, and approach used to identify the guidance. General and specific findings that could be used as guidance by a PM in deciding to use distributed testing for the T&E phase are presented in Section 2.2. Section 2.3 provides cost guidance identified primarily, but not only, from the JADS experience. Section 2.4 presents the proposed WBS with definitions of each element and Section 2.5 provides information on tools that support the use of distributed testing in the T&E phase as well as sources for other pertinent information.

2.1.2 Intended Uses

Originally, JADS requested a cost model to support the development of incorporating distributed testing activities into a project's T&E phase. After further investigation we concluded that this was not feasible given the limited amount of information available from the three JADS tests and other sources. Another factor limiting the use of JADS test data for development of a cost model was that the JADS tests were optimized for experimental objectives and not for evaluating the SUT objectives. Data from these experiments would not necessarily be reflective of an actual test program's experience. As a result, JADS test data could not be used to support development of accurate and reasonable cost estimating relationships (CERs) for actual projects.

In this report, JADS provides PMs and their T&E engineering teams with information on what it identified as cost drivers, risks, risk mitigating strategies, and lessons learned. In some cases, costs encountered in the JADS tests are included for the purpose of providing program cost analysts with an initial data point. Certainly, the T&E community will need to collect much more data before meaningful CERs or cost models can be developed that reflect distributed testing test costs.

2.1.3 Approach

The approach used to identify relevant cost guidance associated with the use of distributed testing in the T&E phase included the following steps.

- Interview JADS members involved in all aspects of the three JADS tests to understand what is required to incorporate distributed testing into the T&E process, that is, the differences from conventional T&E approaches, and to define a new process that considers and possibly uses distributed testing technology.

- Discuss distributed testing applications with other organizations using distributed testing or related technologies including
  - U.S. Army Simulation, Training, and Instrumentation Command (STRICOM) Advanced Distributed Simulation Technology II (ADST-II) Program Office website at http://www.stricom.army.mil/PRODUCTS/ADSTII/;
  - U.S. Air Force Studies and Analysis Agency (AFSAA) Theater Battle Arena (TBA) office website at http://www.afsaa.hq.af.mil/SAM/SAMT/; and
  - Defense Modeling and Simulation Office (DMSO) High Level Architecture (HLA) Federation and Development Process (FEDEP) developers website at http://hla.dmso.mil/hla/federation/fedep/.

- Note that while distributed testing technologies are being used by these and other organizations, none were using it directly in the T&E phase (except the FEDEP developers who supported the JADS EW Test). None of these organizations' distributed testing use fulfilled the more stringent T&E requirements for latency, fidelity, instrumentation and data management. The FEDEP checklist and development of an HLA federation were used on the JADS EW Test.

- Identify elements of a generic T&E portion of a WBS that would reflect incorporation of distributed testing in that phase. This proposed WBS captures activities either new to the T&E phase or that will require modification resulting from distributed testing. The proposed WBS was reviewed by JADS and revised based on their inputs. It was also compared against the DMSO FEDEP Checklist 1, and DMSO *DoD Verification, Validation and Accreditation (VV&A) Recommended Practices Guide*, November 1996.

- We have not attempted to modify WBS elements outside of the system T&E element, but if distributed testing is used for this phase, the PM office (PMO) should identify other areas in the program that would be impacted. For example, systems engineering and program management (SEPM) may need additional resources, while traditional T&E activities may realize savings.

- Gather and analyze JADS experience and map that experience to specific elements in the proposed WBS.

- Identify resources for PMs to access to support distributed testing use in T&E: tools, HLA information, upgraded test ranges, and virtual environments.

- Make recommendations for changes within the DoD community to accommodate future applications of distributed testing technology to T&E requirements.

2.2 Findings

Findings from the cost guidance study are presented in two categories. The first category consists of general findings on distributed testing technology, which could be used in other phases of the program and should be considered during the feasibility analysis. The second category consists of specific findings, which describe characteristics specific to the T&E phase, but that are not specific to one WBS element.

2.2.1 General Findings

- Since JADS was chartered in 1994, enabling technologies associated with distributed testing have made significant progress. One example is the HLA protocol. HLA software, training, and use have increased dramatically. Certification of HLA federates has increased and test ranges are updating to accommodate these new technologies.

- Technology advancements should significantly reduce some of the difficulties reported by JADS. Distributed testing, HLA, and other technologies and protocols are making integrated environments much more feasible and available to the program developer. Integrated synthetic environments allow programs to do more in less time with better results than existing approaches used today.

- Distributed testing technologies support three major DoD initiatives.
  - DoD acquisition reform, DoD Regulation 5000.2, *Mandatory Procedures for Major Defense Acquisition Programs (MDAPS) and Major Automated Information System (MAIS) Acquisition Programs,* requires modeling and simulation to be an integral part of test planning and that T&E planning start in Phase 0;
  - Simulation Based Acquisition (SBA), as defined in the SBA Roadmap produced by the Joint SBA Task Force which was chartered by the DoD Executive Council for Modeling and Simulation (EXCIMS); and
  - Simulation T&E Process (STEP) initiated by the Office of the Under Secretary for Defense, Acquisition and Technology (OUSD(A&T)) in support of acquisition streamlining.

These initiatives are complimented by, and provide support to distributed testing use. As these initiatives are implemented, models and simulations will be developed for the entire program lifecycle and significant costs will not have to be borne by the T&E phase only.

- The DoD life cycle cost model needs to be modified to support T&E activities at the beginning of the program. The sooner distributed testing is started, the sooner design flaws and bugs will be found and changed. As a general rule, the sooner you find a problem, the lower the cost to fix the problem.

- Staff trained in new technical disciplines will be required to successfully implement distributed testing technology. For example, network engineering is critical to the successful application of distributed testing since the instrumentation must be able to account for network availability, bandwidth usage and network induced latency. Another example is the coordination of test control and analysis communications, visual displays, and computer processing capability to ensure integrity of responses, a key factor in T&E exercises.

2.2.2 Specific Findings

Implementing the three JADS tests provided many lessons learned that should be considered and incorporated into the PMO's cost estimate addressing distributed testing.

- In almost all interviews with JADS personnel, strong systems engineering processes including configuration management were identified as key to successful distributed testing, because this testing approach requires significant coordination among many entities within a testing federation.

- Pro-active program management and leadership will encourage team communication, and clear delegation of authority will keep communication lines open.

- Intensive planning is needed to ensure all federates are on schedule for development of or modifications to player representations, test rehearsals and execution, synchronization, and interoperability. Contingency planning will reduce risks.

- Documented requirements and acceptance criteria will support efficiency and cost containment for VV&A activities. VV&A planning should be part of the feasibility analysis and Phase 0 activities. Note, that the verification and validation (V&V) of models and distributed simulations are formally required by DoD Instruction 5000.61, *DoD Modeling and Simulation (M&S) Verification, Validation and Accreditation (VV&A),* before they can be used in testing. Simulations have to go through a V&V process at the federate level and at the federation level.

- Effective data management is essential since distributed testing produces copious amounts of data. A comprehensive data management plan must include explicit information on the data to be collected at each network node, on-site data processing requirements, and data that will be transmitted to the analysis center.

2.3 Cost Guidance

This section gives guidance on factors that should be considered in building a cost estimate for distributed testing and that may drive testing costs beyond available resources. This information is provided in three sections: general cost drivers, risk factors that affect cost drivers, and guidance for specific cost elements in the proposed WBS. (The proposed WBS with definitions is in Section 2.5.)

2.3.1 General Cost Drivers

Several cost drivers were identified during the execution of the three JADS tests that have impact on many cost elements in the proposed WBS. They are listed here to emphasize the importance of preparing and planning for their minimization.

- SE complexity, as defined by the number and types of nodes, interfaces, and bandwidth requirements, will increase costs and risks to all phases of the distributed portion of the test program. Since a major virtue of distributed testing is to support the construction of complex test environments, the test planner must balance the need for complexity against the expense and fragility of the test architecture.

- Fidelity requirements for the models can range from simple, script-driven models to high-fidelity man-in-the-loop simulators. Fidelity and costs are directly proportional.

- The JADS experience was that test ranges and labs underestimated costs 10 to 15 percent. It is recommended that agreements with these organizations be formalized in a statement of capabilities and that they be required to provide detailed cost estimates. The program test's priority number should be provided to the PMO's T&E representative. Additionally, any provisions for schedule-delay penalties should be agreed to. (These penalties are one of the costs of poor scheduling.)

- Test ranges, labs, and other federates should have experienced staff trained in distributed testing and HLA application. If they do not have this capability, increase the cost estimate for elements associated with their support.

- JADS found that configuration management of hardware (HW), software (SW), network interface units (NIU), and models was more important to distributed testing than to traditional testing. A detailed configuration management plan and implementation process should minimize this risk.

- The cost of implementing distributed testing can be significantly reduced if distributed testing is planned for within the larger test program, i.e., while traditional testing approaches are being developed.

- Architecture integration should be fully understood to properly estimate it at the outset of the program. JADS found this activity to be consistently underestimated.

- Legacy test ranges with out-of-date equipment caused significant problems for the JADS tests. This could also be clarified through a formal document from the test range.

- JADS recommends that verification be done on network nodes as they are developed.

2.3.2 Risk Factors Impacting Costs

- Time synchronization, instrumentation and data management are all critical to the success of distributed testing. Planning for their successful implementation will minimize the risk of cost increases.

- Because distributed testing required multiple federates to set up the SE, scheduling and coordination became much more complex and difficult. This characteristic affects all phases of the test program. Careful planning will mitigate some of the risk.

- As in any program, unstable requirements and requirements creep have the potential to increase costs dramatically. A strong systems engineering process that emphasizes thorough requirements analysis and definition will minimize the impact of this cost driver.

2.3.3 Cost Guidance for WBS Elements

One purpose of this study was to develop a robust WBS generic across a broad spectrum of system application domains. While elements in the proposed WBS are relative to using distributed testing technology (either new elements or those that would be modified to accommodate distributed testing technology use), other elements in a program's T&E WBS may be deleted or significantly reduced with distributed testing use.

The following tables are intended to provide a cost analyst with initial information on distributed testing cost elements. Much of this information will support development of range cost estimates given the immature state of relevant cost information for this technology. Included are cost elements that JADS was able to attribute cost information and recommendations relevant to the development of a cost estimate to and do not include all WBS elements defined in the proposed WBS in Section 2.5.

The WBS includes only those elements that have either been added to reflect an activity new to T&E or that will need modification because of inclusion of distributed testing.

The JADS experience provided only three limited examples from which this information has been gleaned, supplemented by information from other sources. This information may not be applicable across the entire T&E spectrum. As stated, this effort is meant to provide an initial step toward developing a cost model that reflects distributed testing activities.

Table 1. Cost Guidance, Risks and Recommendations for WBS Element 1.X.0

WBS Element	Cost Guidance and Risks	Recommendations/Comments
1.X System Test and Evaluation		
1.X.0 Feasibility Analysis (FA)	The FA will require more thorough planning and earlier in the program. JT&E program managers and engineers should be identified and work initiated as part of the first phase of the programs life cycle.	Even if the FA results in a decision to not use ADS technology, it will provide T&E engineers with needed insight into the system's requirements and testing needs and supplant the need for typical initial studies.
1.X.0.1 Test Planning Methodology	Since this element requires in-depth understanding of the SUT requirements, it does require a fair amount of effort. However, some of the effort done in developing this product could support either other T&E products or products developed for the overall program.	Reference the JADS special report, *A Test Planning Methodology-From Concept Development Through Test Execution*, at the JADS website.
1.X.0.2 ROM Cost Analysis	Additional costs for facilities, networking and development and/or modification of entities for required capabilities should be included in the cost estimate.	A range estimate at this stage is appropriate. This approach to cost analysis will provide several attractive uses. First, it will make it easier to arrive at reasonable costs since high, medium and low value estimates are sought, not an absolute value. Second, it can support quantification of risk if the estimated values are identified based on uncertainty.
1.X.0.3 Risk Analysis	Quantifiable risks could be incorporated into the ROM cost analysis through use of a range cost estimating approach. Nonquantifiable risks should be considered and potential outcomes understood to the extent possible for this early stage. Technical and programmatic risks should be addressed.	This analysis should focus on two areas: first, test requirements that cannot be met using traditional test methods and second, the importance of planning, scheduling and coordination of federation members.

Table 2. Cost Guidance, Risks and Recommendations for WBS Element 1.X.1.1

WBS Element	Cost Guidance and Risks	Recommendations/Comments
1.X.1 Developmental Test and Evaluation (DT&E)	This stage of program testing typically is done at the brassboard or system subcomponent level.	
1.X.1.1 Planning	Using ADS technologies requires increased planning because of scheduling and time-critical linkage.	Diligence in planning and stricter adherence to good systems engineering practices, while necessary for ADS use, will enhance the results of the entire T&E program.
1.X.1.1.1 T&E Network Requirement Definition	Complexity of the network architecture will drive this element's costs up since there will be more to examine. Developing the program test plan will require additional effort not typically done for traditional testing.	Complexity is equated to number of nodes, links and required bandwidth to develop the synthetic environment. Complexity will drive costs of the entire T&E test program. During the planning phase, network complexity should be minimized to the extent reasonably possible.
1.X.1.1.1.1 Requirements Identification	Estimating costs for identifying requirements can be initially started using DoD CERs for this activity and should then be modified to the specific program.	
1.X.1.1.1.2 Objectives Development	Complexity of the network architecture will drive costs for this element.	
1.X.1.1.2 Establish Federate Development Team	The number of network nodes will drive costs since entities need to be interacted and coordinated with for its accomplishment.	
1.x.1.1.3 T&E Phase Reporting and Documentation	Documentation will be similar to traditional T&E. Use the same cost estimating relationship used in the rest of the program cost analysis.	Note, this element includes documentation for all DT&E testing.
1.X.1.1.4 T&E Phase Maintenance	T&E phase maintenance costs are expected to be higher than traditional T&E methods because ADS technology is more HW and SW intensive. Actual costs can be estimated based on the bill of materials and amount of SW required for the tests.	While these costs may be higher than for traditional testing HW and SW, it is expected that this cost will be more than offset by a decrease in traditional test costs for maintaining live test equipment.
1.X.1.1.4.1 HW Maintenance	Use vendor maintenance information.	
1.X.1.1.4.2 SW Maintenance	DoD CERs for software maintenance should be applied to estimate this element's cost.	

Table 3. Cost Guidance, Risks and Recommendations for WBS Element 1.X.1.2

WBS Element	Cost Guidance and Risks	Recommendations/Comments
1.X.1.2 Concept Development	This test program phase will require significant coordination effort to gain consensus on scenario characteristics and test objectives. Effort will also be used for federation object model (FOM) and interface control document (ICD) development as well as the test concept.	
1.X.1.2.1 Scenario Development	Scenarios are not limited by test facility or range capabilities. Additional development supports augmentation of these capabilities adding significant capabilities to the test program at some cost. Costs are a variable of the number of entities required.	JADS ETE Test scenario development work is a good example.
1.X.1.2.2 Concept Analysis	Based on JADS experience, costs for this element are more than for traditional testing and are driven by the number of entities that must be included in the analysis.	

Table 4. Cost Guidance, Risks and Recommendations for WBS Element 1.X.1.3

WBS Element	Cost Guidance and Risks	Recommendations/Comments
1.X.1.3 Design and Development	Complexity of the network and fidelity of the models will drive the costs in this phase. This phase will also require coordination among the federates and their adherence to all standards and protocols. Requirement creep or change will cause costs and schedule to exceed estimated values.	The T&E network architecture plans and all plans for development and implementation are completed. Development and/or procurement of HW and SW for networks, protocols, interfaces and TCA are accomplished.
1.X.1.3.1 T&E Network Architecture Design	Costs for this element are strongly impacted by the number of nodes included in the federation. The TCA will require HW and SW investments. JADS TCAC cost about $750 thousand (K) in fiscal year (FY) 97 dollars. The number of nodes will increase the cost of developing the security approach since coordination must include all designated approval authorities (DAA).	
1.X.1.3.1.1 T&E Network Architecture Detailed Design	DoD detailed design CERs should provide a reasonable starting point for estimating this element. Modify the CER as seems appropriate to the case.	
1.X.1.3.1.1.1 Node Site Surveys	Typical CERs can be used for temporary duty expenses to visit the node sites once they are identified.	Costs are driven by number of nodes.
1 X.1.3.1.1.2 Test Control and Analysis (TCA) Definition		JADS TCAC HW and SW costs are approximately $750K in FY97 dollars.
1.X.1.3.1.1.3 Security Approach Development		Increased requirements and coordination with each node's DAA.
1.X.1.3.1.1.7 Test Control HW and SW Selection		Moderately increased cost to provide this HW and SW.
1.X.1.3.1.1.8 Data Collection and Instrumentation Requirements Determination		Tools required to support this element are typically on the high end for test equipment.
1.X.1.3.1.1.9 Time Synchronization Method		It is important that the federation be time synchronized to ensure accurate results.
1X.1.3.1.1.10 T&E Network Architecture Development and Integration Plan		Network architecture is very important and should be designated to minimize complexity, e.g., minimum set of nodes. Architecture integration must be well planned.
1.X.1.3.2 Test Activity Planning	This activity includes some of the VV&A activities. While the cost of this element will vary with the number of nodes required, the JADS experience showed that this was not a significant cost to the test program.	The cost of this element will vary with the number of nodes required.
1.X.1.3.2.2 Perform Detailed Design Verification		Costs driven by the number of nodes.
1.X.1.3.3. T&E Network Architecture Development	JADS had additional costs because of lack of up-to-date simulations and facilities. To contain costs, leverage DIS- and HLA-compliant systems supporting standard data protocols and data interfaces to avoid modifications. The Foundation 2010 Program Office is currently modernizing five OARs and is chartered to do all 21 ranges. DMSO HLA office cites increasing HLA certified systems. These activities should support cost containment for ADS technology users.	Significant time should be spent developing this architecture to ensure success during integration and test activities. Test ranges (TR) included in the federation should provide detailed cost estimates. Cost drivers are TR staff inexperienced in ADS technology and the previous task having little similarity to current ADS task. JADS experience with TR cost estimates was that they were 10 to 15 percent lower than actual costs.
1.X.1.3.3.3 HW and SW Configuration Control Implementation	Costs for this element are strongly impacted by the number of nodes included in the federation and changes to HW and SW throughout the T&E life cycle.	

Table 4. Cost Guidance, Risks and Recommendations for WBS Element 1.X.1.3 (continued)

WBS Element	Cost Guidance and Risks	Recommendations/Comments
1.X.1.3.3.4 Data Protocols	Systems that leverage DIS- and HLA-compliant	

Development	systems avoid developing their own protocols.	
1.X.1.3.3.5 Construct and Assemble Synthetic Environment	Designing and developing software for player representations are a major cost to ADS tests dependent on fidelity and complexity (simple script-driven representations to man-in-the-loop simulators) and can be estimated using typical SW estimating techniques. When assembling the SE, number of nodes and architecture complexity drive the costs.	
1.X.1.3.3.5.2 TCA Design, Build or Procurement	JADS TCAC costs were approximately $750K in FY 97 dollars.	
1.X.1.3.3.6 Simulation Modifications	Simulation costs can be estimated using typical SW estimating techniques.	Modifications may be necessary unless the simulation supports standard data interfaces, e.g., DIS, HLA.
1.X.1.3.3.7 Range Data Processing Modifications	ADS-based tests are data intensive. Test ranges should provide cost estimates for required data processing upgrades.	
1.X.1.3.3.8 Facilities Modifications	Facilities, test ranges and labs should be asked early in T&E planning for detailed estimates of costs to support testing that clearly lay out modification costs the program must bear.	The Foundation 2010 program is modernizing five OARs now and will do all 21 OARs. Other facilities are getting HLA certified. This trend will support ADS technology making it affordable for all programs.

Table 5. Cost Guidance, Risks and Recommendations for WBS Element 1.X.1.4

WBS Element	Cost Guidance and Risks	Recommendations/Comments
1.X.1.4 Installation, Integration and Test (II&T)	Impact on costs is dependent on test requirements and is driven by architecture complexity and required fidelity. ADS is HW and SW intensive and therefore, costs may be higher for II&T than traditional testing.	
1.X.1.4.1 Execution Planning	Use typical DoD documentation CERs for plan developments.	Planning needs to ensure that federates are all available for testing and synchronized. Requires increased coordination with all federation members.
1.X.1.4.1.4 Security Test and Evaluation Plan		Plan may need to address multiple security levels at varying nodes.
1.X.1.4.2 Network (NW) Installation and Testing	Since ADS technology is more network based than traditional test methodologies, this cost element can be high.	ADS-based testing requires NW monitoring tools to support data analysis. These tools can be expensive, e.g., Cabletron's SPECTRUM® SW costs were about $25K (depending on options). Note, this is a tool for NW monitoring and not the actual NW SW.
1.X.1.4.2.1 HW and SW Installation	Since ADS technology is more HW and SW intensive than traditional test methodologies, this cost element may be higher.	
1.X.1.4.2.2 Integration and Testing	This element should be driven by the amount of HW and SW required for the SUT tests, as well as by the fidelity of the models and instrumentation requirements.	
1.X.1.4.3 Components and Networks Integration	The cost of integrating components and networks together will be driven by the architecture's complexity.	
1.X.1.4.4 Synthetic Environment Validation	The cost of validating the SE will be driven by the model's fidelity requirement.	
1.X.1.4.5 Risk Reduction Missions		ADS-specific cost; necessary activity designed to catch problems that could occur during test execution causing multiple test facilities to stay in a holding pattern or possibly loosing the facilities to another program's test.
1.X.1.4.6 Test Environment Accreditation	Low cost impact relative to T&E programs.	

Table 6. Cost Guidance, Risks and Recommendations for WBS Elements 1.X.1.5 and 1.X.2

WBS Element	Cost Guidance and Risks	Recommendations/Comments
1.X.1.5 Test Execution and Analysis	ADS test execution costs could be considerably less than traditional test executions depending on the architecture complexity and fidelity of the model versus the need for relocating large and costly test items. OAR facility costs are expected to be lower for ADS tests than traditional tests.	
1.X.1.5.1 Test Readiness Review	Nominal cost.	
1.X.1.5.2 Test Execution	While it will vary with the architecture complexity, ADS test execution is expected to cost less than traditional test execution. ADS testing provides more test data than traditional testing.	
1.X.1.5.2.1 Test Runs		
1.X.1.5.2.2 Data Collection	Based on the JADS experience, costs for data collection may be about 10 percent less for an ADS-based test versus a traditional test.	
1.X.1.5.3 Results and Feedback	ADS testing allows for more scenarios to be tested and more thorough testing. Better testing across a wider set of objectives results in easier evaluation and reporting.	Free data analysis tools are available from the JADS test efforts.
1.X.1.5.3.1 Data Analysis		Tools required for data analysis are divided into real-time, quick-look and detailed analysis tools. Due to availability of data on the wide area network, tool development is less costly than development of tools for non-ADS tests which requires interfaces to various median and formats. Tools that will provide a majority of the needed real-time and quick-look analyses are available from various sources, including the JADS test efforts, for free. The reader is referred to Section 2.6 of this report for detailed information.
1.X.1.5.3.2 Test Evaluation		Evaluation of ADS-based tests was found to be easier than evaluation of traditional tests because of the amount of data output from the ADS testing methodologies.
1.X.1.5.3.3 Provide Test Results and Evaluation Feedback		This element should be aided by the significant data outputs from ADS methods and should cost less than traditional test efforts.
1.X.2 Operational Test and Evaluation (OT&E)	OT&E testing demonstrates a system's ability to support the services' tactics, techniques and procedures.	OT&E is likely to involve more nodes than DT&E resulting in higher costs relative to DT&E.

2.4 Proposed Work Breakdown Structure (WBS)

This section presents only additional or modified WBS elements identified as specific to incorporation of distributed testing in existing T&E approaches. This WBS is not meant to supplant the entire T&E WBS but only to provide guidance to what additional elements need to be inserted. In some cases these elements are named similarly to elements in WBS for existing T&E approaches, but definitions of the work required to be done reflected in the element are directed toward the use of distributed testing.

This WBS includes tasks required to incorporate distributed testing as part of the T&E process of a program. It is not a stand-alone product. Elements 1.X.1.1 through 1.X.1.5.2 refer to specific activities in which changes to conventional T&E approaches will have to be considered to allow for distributed testing use. It is assumed that developmental and operational tests have similar distributed testing requirements and costs. Therefore, this report provides one set of elements in the WBS that can be used for either test phase. It is also assumed that development and implementation of the distributed testing architecture will be incorporated into the T&E process in the program's Phase 0 in accordance with DoD 5000.2R.

1.X SYSTEM TEST AND EVALUATION (ST&E) - This element refers to the use of prototype, production, or specifically fabricated HW and SW to obtain or validate engineering data on the performance of the prime mission equipment (PME). This element includes the detailed planning, execution, support, data reduction, and reports from such testing (exclusive of those required under data), and all HW items which are consumed, or planned to be consumed, in the conduct of such testing. It includes all effort associated with the design and production of models, specimens, fixtures, and instrumentation in support of the system-level test program. It also includes all planning, management, and coordination of federation developers required to incorporate distributed testing use into traditional T&E methods. Note that distributed testing techniques use simulated models connected via real-time networks. Therefore, the term T&E network, or T&E network components, is used in place of distributed testing in most cases in the following WBS elements and definitions.

Initially, it was planned to develop separate sections of the WBS for DT&E and OT&E, but T&E engineers described similar activities for both test phases. This WBS provides one set of elements that may be used for either developmental or operational testing. For a new project, WBS element 1.X.0, Feasibility Analysis, should be done for the entire T&E program. If the project has already gone through much of the DT&E phase, 1.X.0 should be used to analyze the benefits and utility of using distributed testing technology in the OT&E phase.

1.X.0 FEASIBILITY ANALYSIS - The purpose of this element is to provide the decision maker (usually a program manager) with necessary information, based on quantitative and qualitative analyses, on which a decision can be made to use or not use distributed testing techniques in the program's T&E phase. Also, if distributed testing techniques will be used, this analysis should support identification of how it can best be used to supplement traditional T&E capabilities and what resources may be available and their location.

1.X.0.1 TEST PLANNING METHODOLOGY - An approach to analyzing applicability of distributed testing techniques in meeting a program's test objectives. Included in this approach is a survey of availability of models and simulations, networks, facilities, trained personnel, etc., to support a program's T&E requirements. This analysis should also address the program's required security levels and ability and availability of equipment and personnel who can sustain the program's security integrity. Additional information on this methodology can be found in the JADS JTF technical paper, "An Advanced Distributed Simulation Inclusive Test Planning Methodology."

1.X.0.2 ROM COST ANALYSIS - Perform a ROM cost estimate analyzing cost of incorporating distributed testing techniques into the T&E approach. Costs related to development, modification, and/or procurement of modeling and simulation (M&S), SW, HW, networks, facilities, personnel, training, VV&A, and documentation are some examples of elements that should be included in the estimate.

1.X.0.3 RISK ANALYSIS - Perform an initial analysis of technical and programmatic risks of incorporating, or not incorporating, distributed testing methods into the traditional T&E approach.

This cost element, 1.X.0, leads to a decision point in the program -- to use distributed testing technology with traditional methods or not. Therefore, it is essential that the feasibility analysis be resourced sufficiently to provide solid information to the decision makers. If the decision is to use distributed testing technology, all the analysis will be reused and refined in the T&E planning phase. If the decision is not to use distributed testing technology, it is expected that the results of the analysis would still be of use in the T&E phase.

1.X.1 DEVELOPMENTAL TEST AND EVALUATION (DT&E) - Test and evaluation is conducted on systems to (a) demonstrate that the engineering design and development process is complete, (b) demonstrate that the design risks have been minimized, (c) demonstrate that the systems will meet specifications, (d) estimate the system's military utility when introduced, (e) determine whether the engineering design is supportable (practicable, maintainable, and safe) for operational use, (f) provide test data with which to examine and evaluate trade-offs against specification requirements, life cycle cost, and schedule, and (g) perform the logistics testing efforts to evaluate the achievement of supportability goals; the adequacy of the support package for the system, e.g., deliverable maintenance tools, test equipment, technical publications, maintenance instructions, and personnel skills and training requirements, etc. DT&E is planned, conducted and monitored by the developing agency of the DoD component.

1.X.1.1 PLANNING - The purpose of this section is to initiate the studies and analyses of distributed testing requirements, architecture, resources, and constraints; define objectives; and identify critical systems. As part of the planning effort, organizations that will be used in the simulation federation should be contacted and talks initiated toward achieving the required agreements on responsibilities and schedules. Note that several of these activities will continue definition work started in 1.X.0.1.

1.X.1.1.1 T&E NETWORK REQUIREMENTS DEFINITION - Define T&E network and components test objectives, measures of effectiveness and performance, needed resources, and constraints. Initiate development of plans and procedures for directing architecture and tests toward meeting objectives.

1.X.1.1.1.1 REQUIREMENTS IDENTIFICATION - Develop an initial problem statement from information available at this stage of development and generate an initial requirements list. Define expected VV&A requirements. Information may come from white papers, position statements, and from meeting discussions.

1.X.1.1.1.1.1 CRITICAL SYSTEMS OF INTEREST DESCRIPTION - Develop a clear and unambiguous statement of program needs to include a high-level description of critical systems of interest, required fidelity and resolution of simulated entities, and output data requirements.

1.X.1.1.1.1.2 SUPPORT RESOURCES AVAILABILITY - Identify resources available to support the T&E network architecture (funding, personnel, tools, facilities, etc.).

1.X.1.1.1.1.3 PROGRAMMATIC RISK - Determine known constraints that could affect the T&E network architecture development, e.g., due dates, and security requirements.

1.X.1.1.1.1.4 CONDUCT VV&A FEASIBILITY STUDY - Conduct study to understand the VV&A requirements and identify feasible testing requirements.

1.X.1.1.1.1.4.1 IDENTIFY V&V CONCEPT - Initial conceptualization of the V&V approach and requirements.

1.X.1.1.1.1.4.2 PERFORM CONCEPTUAL MODEL V&V - Validate the conceptual model against the T&E network components requirements.

1.X.1.1.1.1.5 DEVELOP PROGRAM TEST PLAN - Develop the test schedule and requirements for implementation for the program.

1.X.1.1.1.1.5.1 EXPAND V&V CONCEPT - Develop additional details to flesh out the initial V&V concept.

1.X.1.1.1.1.5.2 IDENTIFY COMPLIANCE STANDARDS STATUS - Identify standards and protocols for the T&E network components.

1.X.1.1.1.1.5.3 PERFORM ARCHITECTURAL DESIGN VERIFICATION - Using the preliminary design, identify information (e.g., component level VV&A history, fidelity characteristics) about network components that can assist design decisions. Verify the correctness and completeness of the conceptual model or preliminary design.

1.X.1.1.1.2 OBJECTIVES DEVELOPMENT - Refine the statement of program needs into a more detailed set of specific objectives and plans for the T&E network architecture.

1.X.1.1.1.2.1 TEST OBJECTIVES, SCENARIOS, CONDITIONS AND MEASURES IDENTIFICATION - Develop a prioritized list of measurable objectives for the T&E network architecture. Assess availability of government or contractor furnished equipment, facilities and data. Define operational context constraints or preferences, including geographical regions, environmental conditions, threats, and tactics.

1.X.1.1.1.2.2 PLAN DEVELOPMENT - Develop the T&E network architecture and network implementation plans showing planned schedule and major milestones. Develop the network configuration management plan and data collection test plan.

1.X.1.1.1.2.3 SECURITY REQUIREMENTS IDENTIFICATION - Identify security position, including expected security level and possible designated approval authorities.

1.X.1.1.1.2.4 SUPPORT TOOLS SELECTION - Identify and select tools to support scenario development, concept analysis, configuration management, VV&A, and test activities. Tool selection should be based on tool availability, cost, maintainability, applicability to the given function, and the ability of a given set of tools to exchange data within the T&E network architecture.

1.X.1.1.2 ESTABLISH FEDERATE DEVELOPMENT TEAM - Designate members of federating system's organizations to coordinate development of distributed testing environment including the architecture, federation object model (FOM), interface control document (ICD), schedules, and other test requirements. Define requirements, expectations, test objectives, etc., to provide these organizations with an understanding of what resources are expected from them in personnel, training, equipment, and what costs they may be required to bear. Develop federate coordination process and guidance.

1.X.1.1.3 T&E PHASE REPORTING AND DOCUMENTATION - Document and/or report on all plans and procedures required achieving the objectives of the elements associated with 1.X.1 to include all technical, management, programmatic reports, plans, briefings, engineering drawings, etc.

1.X.1.1.4 T&E PHASE MAINTENANCE - Includes all efforts related to maintenance of T&E-specific items: planning, contracting, and oversight.

1.X.1.1.4.1 HARDWARE MAINTENANCE - Includes maintenance effort associated with T&E-specific HW items.

1.X.1.1.4.2 SOFTWARE MAINTENANCE - Includes maintenance effort associated with T&E-specific SW items.

1.X.1.2 CONCEPT DEVELOPMENT - The purpose of this section is to develop a representation of the real-world domain of interest (entities and tasks) in terms of a set of required objects and interactions.

1.X.1.2.1 SCENARIO DEVELOPMENT - Develop a functional specification of the T&E network test scenario, using the operational context constraints identified in the objectives development (1.X.1.1.1.2) element.

1.X.1.2.1.1 ENTITIES IDENTIFICATION - Identify all entities that must be represented in simulations, or otherwise, by the T&E network architecture.

1.X.1.2.1.2 FUNCTIONAL DESCRIPTION OF ENTITIES - Document functional descriptions of the capabilities, behavior, and relationships between entities over time.

1.X.1.2.1.3 ENVIRONMENTAL IMPACT AND CONDITIONS STUDY - Identify relevant environmental conditions that impact or are impacted by entities in the T&E network architecture including initial and terminal conditions (textual scenario descriptions, event-trace diagrams, and graphical illustrations of force laydowns and communication paths).

1.X.1.2.1.4 CONCEPTUAL MODEL DEVELOPMENT - Select technique(s) for developing the conceptual model (e.g., static process flow diagram, process flow diagrams, correlation tables of objects and activities, descriptive texts) and initiate development to capture all features of the test environment.

1.X.1.2.1.5 FEDERATED OBJECT MODEL (FOM) DEVELOPMENT - Select a FOM development approach and develop the FOM. The FOM development approach should be guided, in part, on the federate members, for example, merging individual federate simulation object models (SOMs), starting from a primary federate SOM and adding objects and interactions, selecting a reference FOM and modifying it.

1.X.1.2.1.6 INTERFACE CONTROL DOCUMENT (ICD) DEVELOPMENT - Addresses critical aspects of the data including byte ordering, precise definition and process for coordinate transformations, context for interpreting data and all other information necessary to create the reference test condition such as threat rules of engagement, the aircraft flight profile, threat locations, and a test condition matrix that is used by a test controller to activate and deactivate threats. While not identified as a product on the FEDEP checklist, the JADS EW Test team found the ICD to be a key document.

1.X.1.2.2 CONCEPT ANALYSIS - Develop an implementation-independent representation of the T&E network architecture.

1.X.1.2.2.1 ENTITY CHARACTERISTICS, RELATIONSHIPS AND INTERACTIONS EVALUATION - Identify all entity characteristics and the static and dynamic relationships between them. Identify behavioral and transformational (algorithmic) aspects of each using the T&E network architecture scenario.

1.X.1.2.2.2 ENTITIES REPRESENTATION - Determine entity characteristics (attributes) and interaction descriptors (parameters).

1.X.1.2.2.3 T&E NETWORK ARCHITECTURE REQUIREMENTS DETERMINATION - Determine T&E network architecture requirements such as data, latency, synchronization, network, interface, test control and monitoring.

1.X.1.3 DESIGN AND DEVELOPMENT - The purpose of this section is to reflect effort required for the detailed design of the test environment to meet the test objectives and ensure adequate data collection; to procure commercial off-the-shelf (COTS) and developmental HW, SW and special purpose interfaces; and to finalize schedules for installation, integration, VV&A, and test execution.

1.X.1.3.1 T&E NETWORK ARCHITECTURE DESIGN - Design the T&E network architecture required to test and evaluate the system.

1.X.1.3.1.1 T&E NETWORK ARCHITECTURE DETAILED DESIGN - Design a federate-wide systems engineering methodology to support T&E network architecture development and integration. This requires close coordination among all facilities and entity participants to ensure a common understanding of the T&E network architecture goals and requirements.

1.X.1.3.1.1.1 NODE SITE SURVEYS - Select T&E network nodes and survey each location. Node selection is based on fidelity, availability, cost, and schedule. Site surveys determine facility communications architecture and requirements and space requirements for tester-supplied equipment and personnel.

1.X.1.3.1.1.2 TEST CONTROL AND ANALYSIS (TCA) DEFINITION - Define required TCA capabilities and optimal locations.

1.X.1.3.1.1.3 SECURITY APPROACH DEVELOPMENT - Perform security risk assessment and develop a security concept of operations.

1.X.1.3.1.1.4 T&E WAN REQUIREMENTS DEFINITION - Define T&E wide area network (WAN) requirements including bandwidth, data rate, acceptable latency, network management/control responsibility, etc.

1.X.1.3.1.1.5 T&E NETWORK COMPONENTS DETERMINATION - Determine if DoD-sponsored networks meet the T&E WAN requirements or if commercial resources are required. If DoD-sponsored common-user services are not feasible, application for waiver from the Defense Information Systems Agency (DISA) and contract for leased lines would be required.

1.X.1.3.1.1.6 T&E NETWORK HW SELECTION - Select HW for the T&E network (routers, channel service units, data service units, multiplexers, encryptors).

1.X.1.3.1.1.7 TEST CONTROL HW AND SW SELECTION - Select test control HW and SW based on the data and voice communications requirements and TCA space requirements and layout.

1.X.1.3.1.1.8 DATA COLLECTION AND INSTRUMENTATION REQUIREMENTS DETERMINATION - Select instrumentation types and data logging SW based on data requirements. Determine HW requirements for data storage and handling (tape drives, compact disks, optical disks). Develop handling procedures for collecting and storing data from the distributed network.

1.X.1.3.1.1.9 TIME SYNCHRONIZATION METHOD DETERMINATION - Determine method for synchronizing time stamps for data loggers. Select synchronization HW and SW.

1.X.1.3.1.1.10 T&E NETWORK ARCHITECTURE DEVELOPMENT AND INTEGRATION PLAN - Complete final version of formalized plan for T&E network architecture development and integration.

1.X.1.3.2 TEST ACTIVITY PLANNING - Identify necessary or required test activities for V&V that will demonstrate that the T&E network will meet its requirements.

1.X.1.3.2.1 DEVELOP V&V PLAN - Continue refinement of the V&V concept and transition information into actionable plan.

1.X.1.3.2.2 PERFORM DETAILED DESIGN VERIFICATION - Verify the T&E network detailed design is correct, complete, and maintains traceability to network requirements.

1.X.1.3.3 T&E NETWORK ARCHITECTURE DEVELOPMENT - Initiate procurement, development, and/or modifications of tools and SW; identify procedures to build the T&E network architecture. Included in this would be any additional player representations needed, DSMs, HWIL labs, range facilities and instrumented live assets, and special purpose interfaces (e.g., network interface units).

1.X.1.3.3.1 T&E NETWORK INSTRUMENTATION PROCUREMENT - Procure or develop network-specific HW tools for network analysis and monitoring including network instrumentation.

1.X.1.3.3.2 SECURE AND ENCRYPTED OPERATIONS PROCEDURE DEVELOPMENT AND APPROVAL - Develop secure/encrypted operations procedures for approval by the designated approval authority (DAA). Achieve formal security accreditation for all network and facilities.

1.X.1.3.3.3 HW AND SW CONFIGURATION CONTROL IMPLEMENTATION - Implement strict HW/SW configuration management control.

1.X.1.3.3.4 DATA PROTOCOLS DEVELOPMENT - Develop standard data protocols to satisfy T&E network architecture communications and interoperability requirements.

1.X.1.3.3.5 CONSTRUCT AND ASSEMBLE SYNTHETIC ENVIRONMENT - Hook federate networks' HW and SW items together (including the TCA) to form the T&E synthetic environment.

1.X.1.3.3.5.1 INTERFACE DESIGN, BUILD, OR PROCUREMENT - Design, build, or procure simulation and network interfaces, runtime infrastructure (RTI) interfaces (if required), and special purpose interfaces.

1.X.1.3.3.5.2 TCA DESIGN, BUILD, OR PROCUREMENT - Based on requirements, design the TCA and develop or procure its infrastructure.

1.X.1.3.3.5.3 PERFORM COMPATIBILITY VERIFICATION - Verify compatibility of network components.

1.X.1.3.3.5.4 PERFORM COMPLIANCE STANDARDS VERIFICATION - Test network components to verify they communicate adequately using the required protocol.

1.X.1.3.3.6 SIMULATION MODIFICATIONS - Identify and implement modifications necessary to use external inputs and to generate required outputs from existing simulations.

1.X.1.3.3.7 RANGE DATA PROCESSING MODIFICATIONS - Identify and implement modifications necessary to meet time-space-position information accuracy, smoothness, and latency requirements.

1.X.1.3.3.8 FACILITIES MODIFICATIONS - Identify and implement modifications required for replay capability to be used during integration testing.

1.X.1.4 INSTALLATION, INTEGRATION, AND TEST - The purpose of this section is to install and integrate the network HW and SW subcomponents and conduct testing to ensure federates, TCA, and network architecture meet interoperability requirements.

1.X.1.4.1 EXECUTION PLANNING - Define requirements to support execution of the T&E network architecture.

1.X.1.4.1.1 INTEGRATION TEST PLAN - Develop integration test plan to support incremental checks on configuration during T&E network architecture build up.

1.X.1.4.1.2 TEST CONTROL PROCEDURES - Develop test control procedures for T&E network architecture integration and test.

1.X.1.4.1.3 DETAILED TEST EXECUTION PLAN - Develop detailed test execution plan for T&E network architecture integration and test.

1.X.1.4.1.4 SECURITY TEST AND EVALUATION PLAN - Develop security test and evaluation plan that defines procedures for testing and evaluating network security.

1.X.1.4.2 NETWORK INSTALLATION AND TESTING - Integrate all participating facilities and entities into one operating environment and verify that all components are interoperable to the degree required to achieve the T&E network architecture objectives.

1.X.1.4.2.1 HW AND SW INSTALLATION - Install and check network HW and SW.

1.X.1.4.2.2 INTEGRATION and TESTING - Integrate all participating facilities and entities into one operating environment and verify that all components are interoperable to the degree required to achieve the T&E network architecture objectives.

1.X.1.4.3 COMPONENT AND NETWORKS INTEGRATION - Integrate all components and networks together in a synthetic environment.

1.X.1.4.4 SYNTHETIC ENVIRONMENT VALIDATION - Examine the ability of the network configuration to represent the intended application's behavior, appearance, performance, fidelity constraints, and interoperability levels.

1.X.1.4.5 RISK REDUCTION MISSIONS - Execute scenarios with fully linked test execution configuration. Include security certification (if required) and evaluation of test control and monitoring procedures, as well as data collection and analysis procedures.

1.X.1.4.6 TEST ENVIRONMENT ACCREDITATION - Based on review of the accrediting authority (i.e., sponsor) the T&E network architecture is accredited for its intended purpose. An accreditation decision for formal acceptance is made.

1.X.1.5 TEST EXECUTION AND ANALYSIS - The purpose of this section is to conduct the tests, collect data, analyze test results, and provide feedback to the PM and developer.

1.X.1.5.1 TEST READINESS REVIEW - Review T&E network architecture to assess readiness for formal testing.

1.X.1.5.2 TEST EXECUTION - Exercise all components of the T&E network architecture as an integrated whole to achieve the test objectives.

1.X.1.5.2.1 TEST REHEARSAL AND EXECUTION - Rehearse and execute the test; generate data according to the test plan requirements.

1.X.1.5.2.2 DATA COLLECTION - Collect data in accordance with approved data collection procedures.

1.X.1.5.3 RESULTS AND FEEDBACK - Analyze test execution data and provide report to PM and developer.

1.X.1.5.3.1 DATA ANALYSIS - Analyze outputs from the test execution phase.

1.X.1.5.3.2 TEST EVALUATION - Evaluate results from the execution phase to determine if all test objectives have been met. If all objectives were not met, identify corrective actions to implement for retest.

1.X.1.5.3.3 PROVIDE TEST RESULTS AND EVALUATION FEEDBACK - Provide test results and analyses to customer.

1.X.2 OPERATIONAL TEST AND EVALUATION (OT&E) - This element addresses test and evaluation conducted by agencies other than the developing agency to assess the prospective system's military utility, operational effectiveness, operational suitability, logistics supportability (including compatibility, interoperability, reliability, maintainability, and logistics requirements), cost of ownership, and need for any modifications. Initial operational testing and evaluation (IOT&E) conducted during the development of a weapon system is included in this element. This element encompasses such tests as integrated system tests, flight tests and sea trials, mobility demonstrations, on-orbit tests, spin demonstrations, stability tests, etc., and support thereto, required to prove the operational capability of the deliverable system. Contractor support (e.g., technical assistance, maintenance, labor material) consumed during this phase of testing is also included in this element.

If distributed testing techniques were used during DT&E, the T&E network architecture can be reused. If modifications are required, some of the planning and preparation elements must be revisited prior to executing the test. If distributed testing techniques were not used for DT&E, all elements from 1.X.2.1 through 1.X.2.5.3.3 must be incorporated into the OT&E effort.

3.0 Conclusion

This section provides links to more information on implementing distributed testing technology and summarizes the report.

3.1 Tools and Resources

This section provides information on tools and resources that support use of distributed testing technologies.

Links to Internet sites are provided to facilitate further investigation of the use of distributed testing technologies. Most of the sources below do not directly address the T&E phase, but do address common issues associated with distributed testing use. This list provides points of contact at several DoD websites but is not meant to be exhaustive.

- Over the five-year lifetime of the JADS JTF, numerous articles, briefings, reports, manuals and tools have been developed and researched in support of the three JADS tests and can be found at http://www.jads.abq.com/html/jads/techpprs.htm.[4]
- Information on tools can be found at http://www.jads.abq.com/html/jads/techpprs.htm#tools.[5]
- Other organizations that are using distributed testing technologies and that might be used in support of a T&E program can be found at http://www.jads.abq.com/html/ads/engine.htm#who.
- AFSAA has been employing distributed testing technologies for a variety of reasons and has been a proponent of their use. More information on AFSAA can be found at http://www.afsaa.hq.af.mil/SAM/SAMT/.
- STRICOM website also has a wealth of information on this topic at http://www.stricom.army.mil/PRODUCTS/ADSTII/.
- DMSO's website has many relevant links to resources. The HLA FEDEP was mentioned above. Another resource is the Modeling and Simulation Resource Repository (MSRR) at http://www.msrr.dmso.mil/.

3.2 Summary

This report provides PMs with findings, conclusions, and lessons learned from the three JADS' tests and others regarding the costs and benefits of using distributed testing. Distributed testing technologies provide new capabilities that potentially help the tester overcome limitations with traditional means of testing.

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[4] After 1 March 2001 refer requests to Headquarters Air Force Operational Test and Evaluation Center History Office (HQ AFOTEC/HO), 8500 Gibson Blvd. SE, Kirtland Air Force Base, New Mexico 87117-5558, or Science Applications International Corporation (SAIC) Technical Library, 2001 North Beauregard St., Suite 80, Alexandria, Virginia 22311.

[5] *Ibid.*

JADS has furthered the T&E community's ability to incorporate distributed testing technologies through the development of tools and methodologies that support its use. It has championed the use of this technology with other legacy products and resources that help mitigate or eliminate risk encountered by PMs. Using both distributed testing technology and traditional test methods in a T&E program provides a more robust and complete system test. Based on the JADS experience the use of distributed testing could not only improve testing but can reduce costs.

4.0 References

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3. Reeves, John and Dr. Larry McKee. *A Test Planning Methodology – From Concept Development Through Test Execution*, November 1999.
4. Richter, G. and Volk, P., AIM-120 Advanced Medium Range Air-to-Air Missile (AMRAAM) Follow-On Operational Test and Evaluation, Phase 3, Part A Test Plan, Air Combat Command, Nellis AFB, Nevada, August 1996.
5. Keck, Eric. *JADS Executive Report on the Utility of Distributed Testing*, December 1999.

5.0 Acronyms and Abbreviations

A/C	aircraft
AASI	Advanced Aircraft Simulation Interface
ACETEF	Air Combat Environment Test and Evaluation Facility, Patuxent River, Maryland; Navy facility
ADS	advanced distributed simulation
ADST	advanced distributed simulation technology
AFATDS	Advanced Field Artillery Tactical Data System
AFB	Air Force Base
AFEWES	Air Force Electronic Warfare Evaluation Simulator, Fort Worth, Texas; Air Force managed with Lockheed Martin Corporation
AFOTEC	Air Force Operational Test and Evaluation Center, Kirtland Air Force Base, New Mexico
AFSAA	Air Force Studies and Analysis Agency
AIM	air intercept missile
AMRAAM	advanced medium range air-to-air missile
ASAS	All Source Analysis System
ATACMS	Army Tactical Missile System
A-tracker	automatic tracker
C4I	command, control, communications, computers and intelligence
C4ISR	command, control, communications, computers, intelligence, surveillance and reconnaissance
CAMPS	Compartmented All Source Analysis System Message Processing System
CD	compact disk
CDT&E	contractor developmental test and evaluation
CER	cost estimating relationships
CM	countermeasures
COTS	commercial off-the-shelf
DAA	designated approval authority
DIS	distributed interactive simulation
DISA	Defense Information Systems Agency
DMSO	Defense Modeling and Simulation Organization, Alexandria, Virginia
DoD	Department of Defense
DSM	digital system model
DT	developmental test
DT&E	developmental test and evaluation
ECM	electronic countermeasure
EDAC	MITRE Corporation's Economic and Decision Analysis Center
EMC	electromagnetic capability
EMI	electromagnetic interference
EOA	early operational assessment
ES	electronic support
ETE	JADS End-to-End Test

EW	electronic warfare: JADS Electronic Warfare Test
EXCIMS	Executive Council for Modeling and Simulation
FA	feasibility analysis
FEDEP	federation development and execution process
FOFSD	follow-on full scale development
FOM	federation object model
FOT&E	follow-on operational test and evaluation
FY	fiscal year
GPS	global positioning system
HITL	hardware-in-the-loop (electronic warfare references)
HLA	high level architecture
HW	hardware
HWIL	hardware-in-the-loop (system integration references)
ICD	interface control document
IIT	installation, integration and test
IOT&E	initial operational test and evaluation
ISTF	installed systems test facility
JADS	Joint Advanced Distributed Simulation, Albuquerque, New Mexico
Janus	interactive, computer-based simulation of combat operations
JMASS	Joint Modeling and Simulation System
Joint STARS	Joint Surveillance Target Attack Radar System
JT&E	joint test and evaluation
JTF	joint test force
K	thousand
LFP	live fly phase
LGSM	light ground station module
LSP	linked simulators phase
M&S	modeling and simulation
MISILAB	Missile Simulation Laboratory, Eglin Air Force Base, Florida
MITRE	company that provides engineering services
MOT&E	multiservice operational test and evaluation
MS	milestone
MSRR	Modeling and Simulation Resource Repository
NIU	network interface unit
NW	network
OA	operational assessment
OAR	open air range
OFP	operational flight program
OT	operational test
OT&E	operational test and evaluation
OUSDA(A&T)	Office of the Under Secretary of Defense (Acquisition and Technology)
PDU	protocol data unit
PGM	precision guided munitions
PM	program manager
PME	primary mission equipment

PMO	program management office
QT&E	qualification test and evaluation
RF	radio frequency
ROM	rough order of magnitude
RPSI	radar processor simulator and integrator
RTI	runtime infrastructure
RWS	remote workstation
SAIC	Science Applications International Corporation
SBA	Simulation Based Acquisition
SE	synthetic environment
SEPM	systems engineering and program management
SIL	system integration laboratory
SIT	JADS System Integration Test
SOM	simulation object model
SPECTRUM®	a network analysis package developed by Cabletron Systems
SPJ	self-protection jammer
ST&E	system test and evaluation
STEP	simulation, test and evaluation process
STRICOM	U.S. Army Simulation, Training and Instrumentation Command
SUT	system under test
SW	software
T&E	test and evaluation
TAC	target analysis cell
TADIL	tactical digital information link
TAFSM	Tactical Army Fire Support Model
TBA	theater battle arena
TCA	test control and analysis
TCAC	JADS Test Control and Analysis Center, Albuquerque, New Mexico
TDP	Time-Space-Position Information Data Processor
TDY	temporary duty
TJU	tactical digital information link (TADIL) J upgrade
TR	test ranges
TRAC	U.S. Army Training and Doctrine Command Analysis Center
TSLA	Threat Simulator Linking Activity
TSPI	time-space-position information
V&V	verification and validation
VSTARS	Virtual Surveillance Target Attack Radar System
VV&A	verification, validation and accreditation
WAN	wide area network
WBS	work breakdown structure
WSMR	White Sands Missile Range, New Mexico

Appendix A
Cost Benefit Analysis for the System Integration Test

A study performed by the JADS System Integration Test team

A.1.0 Introduction

The System Integration Test (SIT) Linked Simulators Phase (LSP) and Live Fly Phase (LFP) distributed testing architectures provided valid results for air-to-air missile test and evaluation (T&E) and have been judged to have utility for several types of missile performance and launcher integration evaluations. Because of the high cost of expending missiles and destroying target drones in live fire tests, a high-fidelity, nondestructive distributed test of the missile has the potential to save significant money, especially if distributed testing is utilized over several phases of test.

This appendix lays out a general methodology for determining the cost effectiveness of implementing distributed testing in a precision guided munitions (PGM) test program and provides a cost savings analysis example. Two approaches to cost effectiveness are addressed: (1) a cost savings approach and (2) a more effective test approach. For the first approach, total testing costs are reduced by replacing a limited number of live fire tests with distributed tests. In the second approach, tests are added without eliminating any live fire tests, so that the total testing costs are higher but with some compensating qualitative benefits.

A.2.0 General Methodology

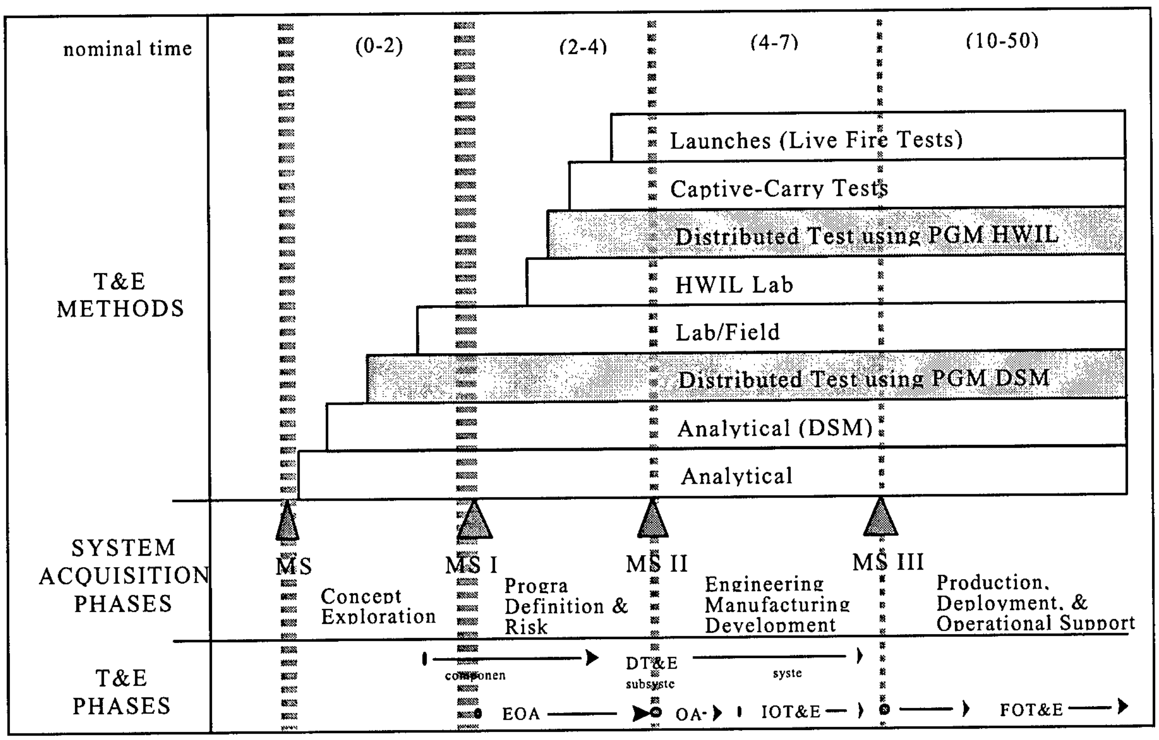
The general cost-effectiveness methodology focuses on qualitative benefits as well as quantitative cost factors. The outline of the methodology is as follows.

- Analyze the appropriate use of distributed testing in the total acquisition and testing program.
  - Estimate the potential benefits of implementing distributed testing.
  - Determine any probable testing constraints that might limit distributed testing implementation.
- Estimate costs with and without distributed testing implementation.
  - If distributed testing results in lower testing costs, quantify cost savings and assess benefits and deficits of distributed testing use. Significant cost savings may outweigh slight deficits.
  - If distributed testing costs about the same, determine the benefits or deficits of using distributed testing.
  - If distributed testing results in higher total testing costs, determine if the benefits justify the increased costs or if other program costs can be traded off.
- Structure an optimal/near optimal distributed testing program based on the appropriate balance between cost savings and qualitative benefits.

The following subsections describe each of the methodology steps in more details.

A.2.1 Appropriate Use of Distributed Testing

The general role of distributed testing in PGM T&E was discussed in Section 3.2.3 of the JADS *Utility of Advanced Distributed Simulation For Precision Guided Munitions Testing* report. Table 1 from that report identified the various performance evaluation techniques used for PGM T&E including distributed tests. Although the discussion in that section focused on the role of distributed testing in PGM developmental test and evaluation (DT&E) and operational test and evaluation (OT&E), distributed testing can support the other testing phases including early operational assessment (EOA), operational assessment (OA), initial operational test and evaluation (IOT&E), and follow-on operational test and evaluation (FOT&E). This is illustrated in Figure A1.



DSM = digital system model HWIL = hardware-in-the-loop MS = milestone

Figure A1. Role of Distributed Testing During PGM System Acquisition and Testing Life Cycle

As Figure A1 shows, a PGM digital system model (DSM) normally becomes available during the initial system acquisition phase, so distributed testing evaluations that use a PGM DSM can begin during this phase (e.g., for requirements development), even before formal T&E begins. As soon as prototype PGM hardware is developed during the second acquisition phase, all T&E methods can begin to be used, as appropriate. As system acquisition proceeds, all T&E methods can continue to be used to test the evolving PGM system and subsystems. The optimal use of the various methods depends on the PGM performance areas being evaluated as Table 2 in Section 3.2.3 in the JADS PGM report shows. Note from Figure A1 above that distributed testing can be used throughout the system acquisition and testing life cycle as PGM simulation resources are developed and refined. Considerations for applying distributed testing to PGM T&E are discussed in Section 4 of the JADS PGM report.

A.2.1.1 Distributed Testing Benefits

In analyzing the appropriate use of distributed testing in the total testing program, the potential benefits of adding distributed testing should be evaluated. General benefits are discussed in Section 3.2.2 of the JADS PGM report and fall into the categories of cost savings, improved testing, and more efficient testing. Potential cost savings are determined in the next step, but any benefits from improved or more efficient testing should be considered before proceeding. These are repeated from Section 3.2.2 of the JADS PGM report and expanded.

- Improved testing benefits.
  - Testing using a linked laboratory distributed testing architecture is more reproducible than live fire testing because scenario conditions are more readily controlled and trials can be replayed for additional PGM responses. This allows more trials to be combined for analysis, giving greater confidence in evaluation results.
  - Testing using manned shooter and target simulators linked to a PGM DSM or hardware-in-the-loop (HWIL) laboratory can be used to realistically evaluate man-in-the-loop reactive countermeasures (CM). This cannot be done in live fire testing because of obvious safety constraints.
  - Distributed testing allows the evaluation of certain classified techniques in which the electronic countermeasures (ECM) device cannot be permitted to radiate its radio frequency (RF) emission on an open range. Rather, the ECM emissions can be restricted to the PGM HWIL laboratory where they are screened from unauthorized observation and where analysts can immediately observe the effects of the ECM on PGM performance.
  - Distributed testing allows the force density of the scenario to be increased. The number of friendly and threat systems can be increased by representing them with either manned laboratories (if realistic man-in-the-loop control of the systems is needed) or DSMs (if scripted behavior is acceptable). The inability to evaluate system performance in combat-representative environments is a common limitation in OT&E and an area in which distributed testing can improve the operational test (OT) environment.
  - Distributed tests exhibit more realism than either analytical simulation models (because actual hardware is used) or stand-alone HWIL laboratories (because realistic shooter and target inputs are provided).
  - The live shooter-target distributed testing architecture can be used for realistic engagement tactics development and evaluation.
- More efficient testing benefits.
  - Shooter/PGM integration can be effectively evaluated using distributed testing configurations.
    - Integration check-out can begin early in the acquisition cycle before a complete PGM system is available by using the linked laboratory distributed testing configuration and

including only key PGM subsystems in the PGM HWIL laboratory. Note that this same configuration can also be used to verify the integration of a new shooter platform to an existing PGM system.
  - If the PGM receives data link support from the shooter during its flyout, the live shooter-target distributed testing configuration can be used to accurately evaluate the quality of the support messages.
- Testing using a live shooter-target distributed testing architecture is more efficient than live fire testing because the analysts get immediate feedback on each trial of a multiple trial mission. This allows adjustments to be made to the remaining test matrix, if necessary, while the live shooter and target platforms are still on range. This "analyst-in-the-loop" feature of distributed testing would be especially useful in efficiently progressing through an ECM testing matrix which involves varying a number of ECM-related parameters. (Up to 15 trials were executed during each two-hour SIT LFP mission.)
- Live fire tests can be realistically rehearsed using distributed testing. This would ensure the proper setup of the scenario and reduce wasted live fire attempts in which the proper scenario conditions are not achieved or would result in anomalies (i.e., cost avoidance). This use of distributed testing would also reduce the risk of a live fire testing program by identifying scenarios which cannot be correctly executed or which cannot achieve the stated objectives.

Also, distributed testing implementation may benefit other parts of the PGM acquisition program besides testing. Distributed testing using a DSM to represent the PGM may aid in requirements development, and resources developed during distributed testing implementation may be useful for training. Such benefits of distributed testing implementation that are beyond the normal scope of testing should also be considered in this determination.

A.2.1.2 Distributed Testing Implementation Constraints

Constraints and limitations in applying distributed testing must be considered when determining the appropriate use of distributed testing. These include any constraints in using the candidate PGM simulation being considered for linking and any distributed testing-related constraints as discussed in Section 3.3 of the JADS PGM report. The result of considering these constraints will be a determination of which PGM test scenarios and conditions can be adequately evaluated using distributed testing (i.e., which scenarios/conditions are feasible candidates for distributed testing).

A.2.2 Test Program Costing

As discussed in Section 3.2.2 of the JADS PGM report, the benefits of distributed testing are best realized when this technique is added to a total PGM testing program and are used to supplement, rather than replace, other testing techniques. Therefore, a total testing program should be developed with and without distributed testing. Major cost elements for each testing technique are as follows

- Nonrecurring costs. Each testing technique will require development and verification before PGM testing can begin. The cost of implementing distributed testing can be significantly reduced if distributed testing is planned for as the other testing resources are developed (so that no major modifications of other resources, such as HWIL laboratories, will be needed for distributed testing implementation and interface costs will be minimized).

- Live fire tests. The most significant recurring costs are for the PGM, target drone, and test range support.
- Captive-carry tests. The main recurring cost is for test range support including use of the shooter and target platforms and the captive-carry PGM pod.
- Stand-alone HWIL tests. The main recurring cost is for HWIL facility operation.
- Distributed testing using live shooter-target configuration. The recurring costs combine the cost of a captive-carry mission and stand-alone HWIL tests with the cost of any additional real-time processing of the data transferred from the live platforms to the PGM HWIL laboratory. As a result, this type of distributed test will usually cost more than just a captive-carry mission combined with a stand-alone HWIL test in which data captured from the captive-carry mission are replayed to drive the HWIL laboratory post-mission.
- Distributed test using linked HWIL laboratories. The recurring costs will be the sum of the costs for operating each laboratory plus the cost of any additional real-time processing of the transferred data.

The cost elements are combined with proposed testing programs which either implement or do not implement distributed testing in order to determine the total costs of the two candidate programs (with and without distributed testing).

A.2.2.1 Cost Savings Case

The largest potential cost savings occur when distributed tests are used to replace some of the live fire tests. Typically, the cost of the PGM and the target drone are much more than the range support cost (e.g., the Advanced Medium Range Air-to-Air Missile [AMRAAM] missile and QF-106 drone cost about $550,000 compared to about $50,000 for range support). The replacement of a live fire test with distributed testing essentially saves the cost of the PGM and target, since the range support cost for the live test is nearly the same as the recurring cost of the distributed test.

However, there are limitations in eliminating live fire tests, because public law requires some live PGM testing and because usually a minimum number of live shots are needed to evaluate the PGM reliability. If the number of live shots is already at the minimum needed for the reliability evaluation, then none of the live shots can be replaced with distributed testing. In this case, the blending of distributed testing into the PGM testing program will normally result in increased cost (unless the distributed tests can replace some of the nondistributed simulation testing at no additional cost), and the benefits of using distributed tests must be carefully evaluated against the increased costs.

If some of the live fire tests can be replaced with distributed testing without impacting other testing requirements (e.g., the reliability determination), then the maximum allowable number of replacements is determined. The test matrix/scenarios/conditions are then examined to determine which of these are best accomplished using live fire tests and which can be adequately tested using distributed testing (see Section B.2.1.1) up to the maximum allowable number of replacements. Note that each live fire test can only evaluate a single scenario, but that each distributed test mission can usually evaluate multiple scenarios (e.g., during LFP testing, a single two-hour mission consisted of about 15 separate passes, each of which could have used a separate profile/scenario) or repeat the same scenario multiple times for added confidence. Hence, there can be considerable leverage in replacing live shots with distributed tests (more test conditions/trials can be evaluated at a lower cost).

A.2.2.2 No Cost Savings Case

For testing programs in which no live fire tests can be eliminated, it may be possible to add distributed testing without increasing the total testing costs. Replacing some of the tests using stand-alone simulation techniques with distributed tests would do this. As discussed in Section 3.2.3 of the JADS PGM report, there are some cases in which distributed tests allow PGM performance areas to be evaluated which could not be evaluated using the PGM simulation in a stand-alone configuration. This is especially true for those cases in which it is necessary to provide man-in-the-loop shooter and target inputs to the PGM simulation.

In general, each distributed test will cost more than the corresponding stand-alone simulation test. Thus, in order to keep the total testing costs constant, it will be necessary to only replace a fraction of the stand-alone tests, and the distributed test cases must be carefully selected to be only those that require linking for valid results.

Even in those cases in which some live fire tests can be replaced with distributed tests, the preference may be to keep the total testing costs constant by adding the appropriate number of distributed missions to replace each live test. This would allow many more test scenarios/conditions to be evaluated during the testing program. For example, results from the SIT LFP show that when the cost of an AMRAAM missile and a QF-106 drone are considered, a single live AMRAAM live fire test could be replaced by about ten distributed tests that use the LFP distributed testing architecture at no additional cost. Further, each of these two-hour distributed testing missions can normally execute about 15 passes. Hence, for this example, it would be possible to trade off one live fire test profile against 150 distributed test profiles. The result would be greater confidence in the results of the PGM evaluation.

A.2.2.3 Cost Increase Case

When distributed tests are merely added to a total testing program without replacing any of the other testing techniques, the total testing costs will increase. In this case, as in the no cost increase case, it is necessary to carefully select test scenarios/conditions for distributed testing implementation and to thoroughly evaluate the added benefits of using distributed testing versus the increased costs. A potential benefit that should be considered by the PGM program manager is cost avoidance because of reduced risk. If improved testing in any program phase would result in a significant reduction in the risk of redesign or redevelopment, the program manager could trade off the cost avoidance against the investment in distributed testing.

Using distributed testing would not necessarily result in an increase in the total cost of the PGM acquisition program in this case. Because of the benefits of adding distributed testing, the PGM program manager should consider trading off other program costs (e.g., those for requirements definition or training, since distributed testing configurations may be able to assist in these areas) in order to implement distributed testing without increasing the total program cost.

A.2.3 Optimal Distributed Testing Program

After completing the analysis in the previous methodology step, it should be straightforward to construct the optimal distributed testing program. Cost savings, qualitative benefits, or a combination of these would justify the resulting program.

A.3.0 Cost Benefit Examples

A.3.1 Cost Elements Example

Data were collected during the SIT LFP for the costs of implementing the LFP distributed testing architecture; conducting AMRAAM testing using this architecture; and conducting AMRAAM testing using traditional, nondistributed testing techniques. The approximate costs for executing each testing technique are as follows (test planning and data analysis costs are not included).

- Live fire test cost: about $600,000 including the cost of the AMRAAM and target drone ($600,000 per pass)
- Captive-carry flight test cost: about $24,000 for a two-hour mission that can perform 15 passes ($1600 per pass)
- Stand-alone HWIL mission cost: about $7,000 for a two-hour mission that can nominally perform 25 runs ($280 per run)
- LFP distributed testing mission cost: about $44,000 for a two-hour mission that achieves 15 passes (~$2900 per pass)
- LFP distributed testing implementation cost: about $2 million including the cost of developing the special-purpose Advanced Aircraft Simulation Interface (AASI), modifying/upgrading Eglin Air Force Base, Florida, range capabilities and facilities, and integration testing. Note that a portion of the cost was for upgrading Eglin range capabilities (e.g., Time-Space-Position Information Data Processor [TDP] improvements) and that these costs would not normally be borne by the PGM testing program

Cost data are also available for the linked laboratory distributed testing configuration as implemented in the SIT LSP. In comparing to LFP costs, it should be remembered that the LSP configuration included an air intercept missile (AIM)-9 Sidewinder, rather than an AIM-120 AMRAAM, HWIL laboratory.

- LSP distributed testing mission: about $20,000 for a four-hour mission that achieved 80 runs (~$250 per run)
- LSP distributed testing implementation cost: about $1.2 million including the cost of modifying Point Mugu/China Lake, California, facilities and integration testing. This cost reflected the need to retrofit the existing facilities so that they could be linked. If the

requirement for linking was planned into the facilities design, it is believed that the cost of implementing linking would have been significantly lower

A.3.2 Testing Program Cost Example

As an example of estimating the cost of a testing program with and without distributed testing, a live fire test program without distributed testing is compared to a test program in which (1) some of the live tests are replaced with distributed tests and (2) a distributed testing configuration is used to rehearse the live tests.

For the specific example, the AMRAAM FOT&E[3A] test plan[6] was examined to determine the maximum number of launch profiles for which the SIT LFP distributed testing architecture could provide valid data. Criteria for selecting candidate profiles included F-15 or F-16 shooter, no multiple shooters with simultaneous launches, fighter drone targets, resolved targets (if multiple targets were involved), no target beam maneuvers during missile intercept, and no chaff CM. Out of 29 live profiles, three met the screening criteria and were feasible candidates for distributed testing implementation. In other words, a maximum of three FOT&E[3A] profiles could be performed using the LFP distributed testing configuration rather than live fire. For each live fire profile replaced with a distributed testing mission, the cost savings was about $550,000. Thus, about $1.65 million could be saved if all three live profiles were performed with distributed testing missions. (Note that even though each distributed testing mission can include 15 passes, it was not possible to combine all three live profiles into a single distributed testing mission. This was because of differences in shooters and other key scenario features in the three profiles.)

The live fire profiles in FOT&E[3A] were rehearsed using captive-carry missions. Data collected from the captive-carry missions were normally used after the mission as inputs into an AMRAAM DSM for the purpose of verifying the launch profiles and missile flyouts. If this was done using the LFP distributed testing configuration instead, the Missile Simulation Laboratory (MISILAB) HWIL laboratory would provide higher fidelity missile flyout results during the mission allowing real-time verification and refinement of the live fire profiles. For each captive-carry mission replaced by the distributed testing configuration, the additional cost was about $20,000. Assuming all three live profiles which could be replaced by distributed testing were indeed replaced and the 26 remaining live profiles were all rehearsed using the distributed testing LFP configuration, the additional cost for the rehearsals would be about $460,000 (three profiles which would have been rehearsed using captive-carry missions were eliminated, saving about $60,000), and the net cost savings from reducing the number of live shots would be about $1.2 million.

Note that the nonrecurring implementation cost for the LFP distributed testing architecture was about $2 million. When this investment cost is also considered, the maximum use of distributed testing in support of FOT&E[3A] would have cost an additional $350,000 if distributed testing

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[6] Richter, G. and Volk, P., AIM-120 Advanced Medium Range Air-to-Air Missile (AMRAAM) Follow-On Operational Test and Evaluation, Phase 3, Part A Test Plan, Air Combat Command, Nellis AFB, Nevada, August 1996.

were only used to replace three of the live profiles and an additional $870,000 if distributed testing were also used to rehearse all live profiles.

This example illustrates that if distributed testing is only used to support one phase of testing involving a relatively small number of live fire tests, cost savings may not be possible. If distributed testing is instead implemented over all phases of testing, cost savings would be expected. For example, the analysis of the FOT&E[3A] profiles showed that about 10% of them could be replaced with distributed testing. If this same percentage is applied to a total missile testing program consisting of 100 live shots, then the number that could be replaced would be ten. In this case (assuming the same costs as for AMRAAM FOT&E[3A] and the SIT LFP), there would be a cost savings of about $1.9 million (after accounting for the $2 million distributed testing implementation cost) if the distributed testing configuration was also used to rehearse all 90 live profiles and a cost savings of about $3.7 million if the distributed testing configuration was not used for rehearsal. The increased cost savings with each replaced live shot are illustrated in Figure A2 (for the case of not using the distributed testing configuration for rehearsal). Note that the break-even number of reduced live shots is four (i.e., this number of reduced shots is required to recover the $2 million distributed testing development cost).

The examples in this section are meant only to illustrate the application of the cost benefit analysis methodology and should not be considered as general results. Each specific PGM program must be analyzed to determine the cost effectiveness of distributed testing implementation. In particular, if distributed testing implementation is properly planned for early in the acquisition and testing program, the cost of implementation may well be significantly lower than the $2 million distributed testing development cost in these examples. (Note that implementation costs are indeed strongly dependent on the specific distributed testing architecture -- the SIT LSP development cost was about $1.2 million versus about $2 million for the SIT LFP.)

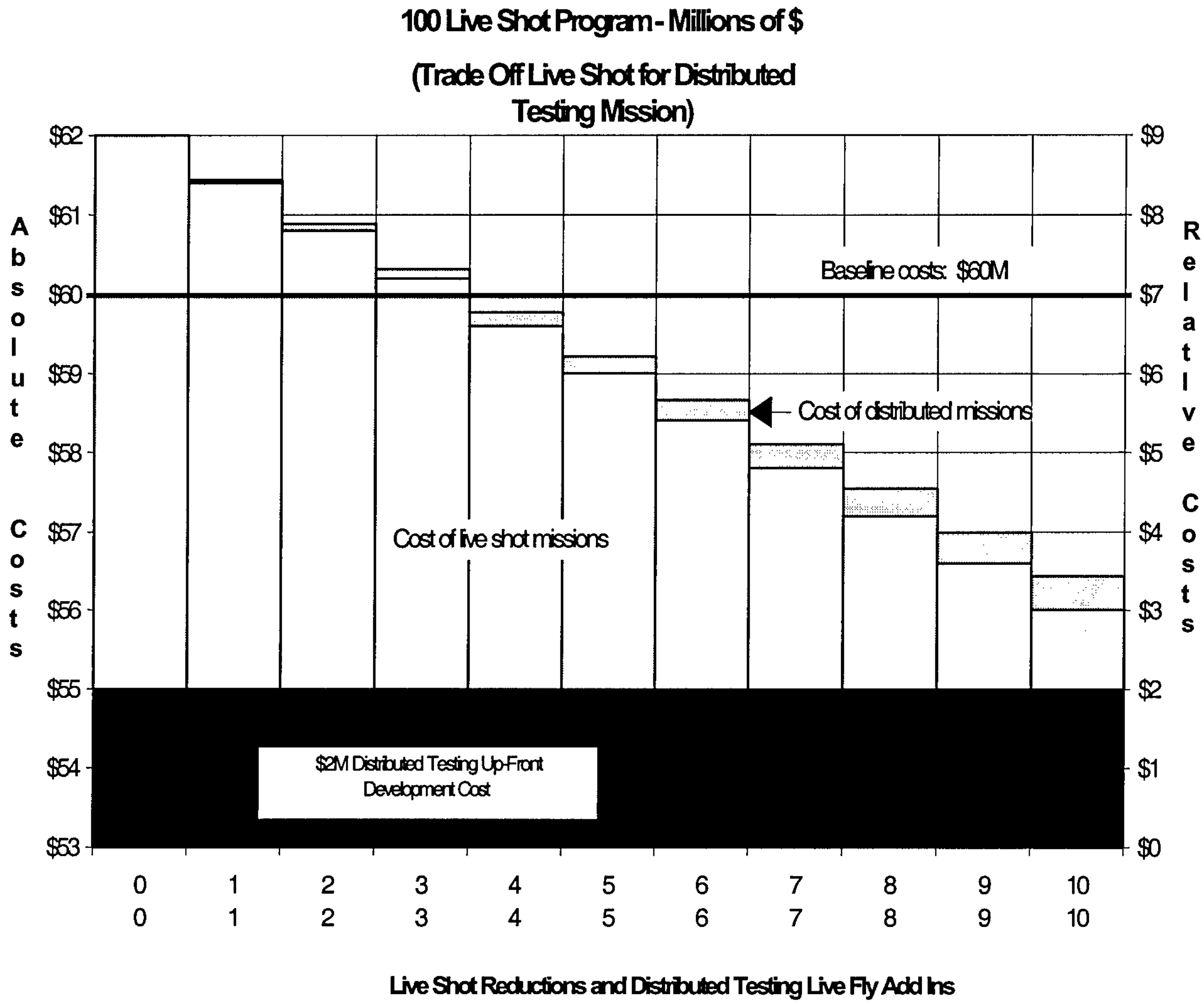

Figure A2. Levels of Program Costs/Savings With Varying Numbers of Distributed Testing Replacement Missions

A.4.0 Conclusion

A general methodology has been presented for analyzing the cost effectiveness of implementing distributed testing in a PGM testing program. The application of this methodology should always be done in a total program sense in which distributed testing is blended into the entire PGM acquisition and testing program. If the strengths and benefits of distributed testing are properly exploited, it should be possible to design an improved, more thorough, and higher confidence test and evaluation program, while still remaining within budgetary constraints.

Appendix B
Cost Benefit Analysis for the End-to-End Test

A study performed by the JADS End-to-End Test team

B.1 Follow-On Full Scale Development (FOFSD) A-Tracker Testing

One of the key issues surrounding the evaluation of the utility of distributed testing is the cost benefit of using it to augment testing of a command, control, communications, computers, intelligence, surveillance and reconnaissance (C4ISR) system. The JADS End-to-End (ETE) Test team chose the ETE developmental test (DT) as the most appropriate test to attempt to compare the costs and benefits of this type of testing with traditional methodologies. The ETE DT was designed as a series of contractor investigative tests of the tracker software functions of the E-8C operation and control subsystem. Each of the tests evaluated the performance of the tracker software against a ground scenario based on the system specifications of the aircraft. This test was compared to the tracker testing conducted by the contractor and the Joint Surveillance Target Attack Radar System (Joint STARS) Joint Test Force (JTF) during the FoFSD phase of the contract. This report will identify the components and scope of the FoFSD tests, the components and scope of the ETE DT and the single planned flight test for the tracker function. Costs to execute the test are reported in the form of types of hours used to conduct the tests. Actual dollar values are not discussed. Benefits are based on the number of test cases supported in each test and the limitations of each test methodology.

B.2 Test Requirements

The E-8C tracker is a software function that allows the operator to initiate and track a group of moving targets and to maintain the track for the operator. The specifications for the aircraft identify the performance requirements for the tracker based on ground operations. A test case for the tracker consisted of some combination of the following.

- Type of formations
  - Convoy
  - Block
  - Line abreast
- Number of vehicles
- Spacing between vehicles
- Speed of vehicles
- Type of maneuvers
  - Turns
  - Slowdown/speedup
  - Stops and starts
  - Cartographic

The combination of the above specifications yielded 204 test cases.

B.3 FoFSD Testing

During FoFSD, Northrop Grumman and the JTF conducted seven dedicated flight tests to verify compliance with the specifications. Three of these tests were contractor developmental test and evaluation (CDT&E) and four of the tests were government-run formal qualification test flights. Each of the tests was flown over the range at Eglin Air Force Base (AFB), Florida. The test wing at Eglin AFB supplied instrumented vehicles and drivers to the test. The ability to test each of the 204 test cases was limited by the size of the range (3.5 total miles with approximately one mile usable for testing) and range safety issues. The size of the range limited the number of vehicles used in a test, the formations that could be used and the type of maneuvers that could be conducted. Range safety limited the spacing between the vehicles and the speeds that could be used. The following is a review of the data on these flights.

No	Type of Flight	Flight	Hours	A/C Personnel	A/C Personnel Required	Drivers and Observers	Test Cases
1	CDT&E	22	7.7	25-29	10	5	N/A
2	CDT&E	27	7.1	25-29	10	5	N/A
3	CDT&E	39	7.2	25-29	10	5	N/A
4	QT&E	N/A	6.9	25-29	8-10	5	N/A
5	QT&E	198	7.2	26	8	26-27*	3
6	QT&E	206	5.8	24	9	15	2
7	QT&E	222	6.9	26	9	26-27*	3

A/C = aircraft **N/A - information not available QT&E =qualification test and evaluation**

*** Flights 198 and 222 included a light aircraft as a ground target**

The following is a summary of the cost benefit factors of the previous flight testing.

Number of test flights	7
Length of test flights	5.8 hours - 7.7 hours
Number of personnel in the aircraft	24-29
Number of vehicles on the ground	4-21 (one light aircraft on two flights)
Number of drivers and observers on the ground	8-27
Test cases performed per flight	2-3

B.4 Live Fly Test Limitations

The Eglin AFB test range was the most limiting factor to conducting live tracker tests. The 3.5-mile test run only provided approximately 1800 meters of usable test run. This is due to the length of time required to get the entire group of vehicles up to speed and at the correct spacing and the length of time required for them to slowdown and stop. This limitation impacts the number of vehicles that can be part of a convoy. The width of the range also limits the number of vehicles that can be in a line abreast formation. The width also denies the ability to test block formations.

Range safety issues require slower speeds and wider spacing than the specifications required. Likewise, the relative inexperience of the drivers resulted in their inability to maintain spacing during maneuvers. Currently, Eglin AFB is limited to fielding 20 ground positioning system (GPS)-equipped vehicles. For one test, Eglin provided 20 GPS-equipped vehicles and 10 additional vehicles equipped with another time-space-position information (TSPI) system; however, this test was the most expensive test that had been tried and will probably not be repeated. Because of costs, most tests are limited to 10 or fewer ground vehicles. Repeatability of these tests was limited by both driver accuracy and by weather conditions at Eglin AFB.

B.5 Distributed Testing

Distributed testing uses a combination of a rigorous test of the tracker using a distributed test environment and a single test flight to verify continued performance of the tracker. The increasing cost of flight tests has forced the Air Force to reduce the number of flights available for testing upgrades and for regression testing. The tracker investigations are being conducted as part of the tactical digital information link (TADIL) J upgrade (TJU) program for the E-8C. Prior to considering distributed testing, the JTF had already accepted the need to reduce testing to a single flight. The cooperative effort between JADS, Grumman, and the JTF provided an opportunity for expanded testing of the tracker while allowing JADS to evaluate the utility of distributed testing to a development test.

The distributed testing environment for the tracker test consisted of a scenario generation and transmission capability at the JADS Test Control and Analysis Center (TCAC), a scenario logger and playback capability in the JADS laboratory at Grumman, and a version of the JADS-developed Virtual Surveillance Target Attack Radar System (VSTARS) located in the Operation and Control Test Laboratory at Grumman. The distributed testing synthetic test range was laid out using a Southwest Asia terrain file. Terrain features had been modified to increase the movement fidelity.

Grumman analyzed the tracker system requirements and produced a set of requirements for vehicles and their movements. JADS ETE Test personnel translated these requirements into constructive simulations of all 204 test cases implemented using the Janus 6K scenario driver. These simulations provided high-fidelity movement of the vehicles using 12 scenarios: accuracy; continuity 1, 2, and 3; block formation 1, 2, and 3; line abreast 1, 2, and 3; in-line traffic and cartographic.

Once the scenarios were developed and documented, they were transmitted from the TCAC facility to the logger at Grumman. During these downloads, data were collected for further analysis of latency and protocol data unit (PDU) dropout rates.

After the scenarios were logged at Grumman, the Grumman logger was switched to an internal local area network for connection to a version of VSTARS that had been integrated with the TJU build of software. Each scenario was played and the test engineers/operators established tracks and collected data. The scenarios could be replayed to obtain greater numbers of data samples.

The following summarizes the cost benefit factors of the distributed testing.

Number of test flights	1
Length of test flight (estimated)	7 hours
Number of personnel in the aircraft	10-29
Number of vehicles on the ground 4-21	4-21
Number of drivers and observers on the ground	8-27
Test cases performed during flight	2-3
Number of distributed testing sessions	12
Total length of test sessions	27 days
Number of personnel conducting test	2-3
Test cases performed during distributed testing	204

B.6 Conclusions

Inadequate range facilities, range safety issues, and insufficient numbers of and the high costs associated with the test assets limit traditional means of testing C4ISR systems, especially those using sensor systems that cover a large area of the battlefield, such as Joint STARS. As this cost benefit example illustrates, distributed testing technology can eliminate many of these conventional testing limitations Using distributed testing, testers can cost effectively conduct more test trials for longer periods of time. For example during the Phase 2 test, the ETE Test team was able to conduct five test trials, lasting six hours each, within a 5-day period. A maximum of three trials could have been conducted using the test aircraft. If additional shifts of operators were available, the test trails could have lasted longer at little additional cost. Because of scheduling issues, crew rest, and the lack of test aircraft, it would be difficult to extend a live test trial beyond five to six hours on station. Comparison of the cost benefit factors of the previous FoFSD live flight and the cost benefit factors of distributed testing shows that distributed testing can realistically test C4ISR systems:

- in larger battle spaces
- with larger numbers of ground-based entities
- under realistic, but unsafe conditions
- using multiple repetitions of the same test scenario without competing for scarce (i.e. expensive) test aircraft and range resources